International Conference on Unmanned Aircraft Systems
(ICUAS 2024)

June 4-7, Chania, Crete, Greece

Technical Program and Book of Abstracts

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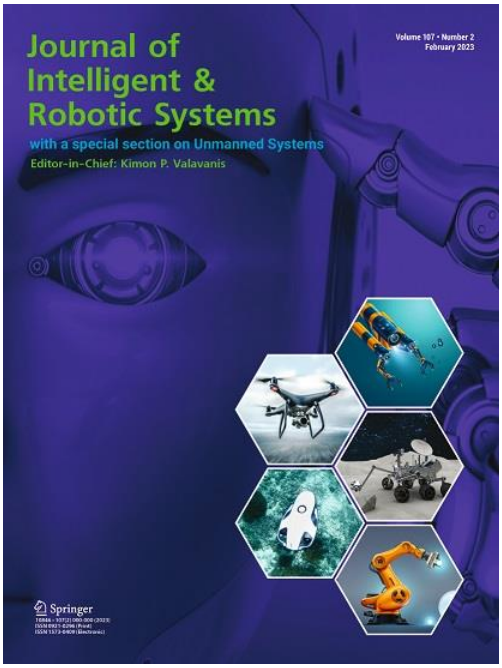

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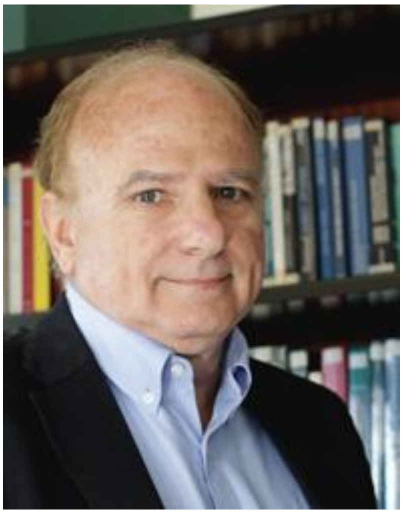
ICUAS 2024 is organized in honor of

Dr. Prof. Anibal Ollero

for his contributions to unmanned aviation



Professor, Head of GRVC
Ingeniería de Sistemas y Automática Department
University of Seville
Scientific Manager of the Center for Aerospace Technologies (CATEC)

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Welcome Message from the ICUAS Association

Dear authors, participants, and attendees:

On behalf of the ICUAS Association Inc., and in my capacity as the President of the Association, it is a privilege, a great pleasure and an honor to welcome you to the *2024 International Conference on Unmanned Aircraft Systems* (ICUAS'24). ICUAS'24 takes place in Chania, Crete, Greece, under the auspices of, and it is sponsored by, the Technical University of Crete (TUC). The Conference is organized for the first time in the historical Center of Mediterranean Architecture (KAM), which is hosted in the *Great Shipyard* (*Megalo Arsenali*) of Chania - it is the last of the 17 shipyards located in the Venetian port of the Old Town of Chania. ICUAS'24 is a 'physical presence only' Conference.

We look forward to your active involvement in the Association and in the Conference, and to your contributions and feedback. We welcome your participation, and we are open to your ideas and suggestions.

I offer my best wishes for a successful and productive event. I look forward to seeing all of you in Chania, and I also look forward to continuing working with you.

Kimon P. Valavanis

Welcome Message from the ICUAS'24 General Chairs

Dear participants and attendees:

On behalf of the 2024 ICUAS Organizing Committee, it is a privilege and a great pleasure to welcome you to this year's Conference, which is organized under the auspices of the Technical University of Crete. The Conference is a four-day event, with Tutorials / Workshops on the first day, followed by the three-day technical Conference.

Conference participants represent academia, industry, government agencies, lawyers, policy makers, manufacturers, students, and end-users, all having deep interest in the state-of-the-art and future directions in UAS/RPAS. In response to the Call for Papers, we received 313 contributed, invited session, and poster papers. The Technical Program includes 160 contributed papers, 24 invited session papers, and 11 poster papers that have been accepted for presentation and inclusion in the Conference Proceedings. As in previous years, all papers were also checked following the *iThenticate Document Viewer Guide* before the final decision was made.

We have assembled a full three-day top-quality Technical Program. We also have four Plenary Lectures in which the keynote speakers address pressing and important issues related to several aspects of unmanned aviation. ICUAS'24 also includes the UAV Competition, which is student focused, offering unique opportunities for students to test and compare their skills with those of their peers, worldwide.

The Organizing Committee members, the Associate Editors and the reviewers have devoted an enormous amount of time and effort to assemble an exciting, informative, and educational Conference. We are thankful to all for their dedication and professionalism.

The paper peer review process was very thorough and in-depth. It was coordinated by the Program Chairs, who assign groups of papers to the Associate Editors, and the Associate Editors choose qualified reviewers to review all papers. We thank all of them for their extremely valuable contributions and dedication. All papers were submitted through the PaperCept Conference Management System. Dr. Pradeep Misra is the 'glue' who keeps all Conference components together. We would not have been able to complete the paper review process without his help, and for this, we thank him wholeheartedly.

We thank all the authors for your participation and contributions. We hope you enjoy the Conference, as well as Chania. Take this opportunity to mix business and pleasure; Chania and Crete have many things to offer.

With our warmest regards,

Nikos Tsourveloudis and Didier Theilliol

Welcome Message from the ICUAS'24 Program Chairs

Dear participants and attendees:

Welcome to ICUAS'24. This year we received 313 contributed, invited session, and poster papers. The paper review process has been extremely thorough and rigorous. All papers were also checked for originality using the *iThenticate Document Viewer Guide*. Our goal was for each paper to have at least three (total) reviews, counting the reviews of the Program Chairs and the Associate Editors. We met and exceeded this goal; the aim was simply to make just and informed decisions and select the best papers for presentation and inclusion in the Conference Proceedings.

The Technical Program includes 195 contributed, invited and poster session peer reviewed papers. The acceptance ratio is about 62%, which, consequently, and it is the lowest since the beginning of the Conference. The Technical Program spans three days, during which all accepted papers are presented.

We would like to thank all the authors for their contributions. The rigorous review process would not have been possible if we did not have such a strong community of expert reviewers. We thank all reviewers for their professional service. Dr. Pradeep Misra helped us in working and effectively using the online paper submission and review system. This system is very sophisticated and yet very practical to use for both small- and large- scale Conferences. It is very hard to imagine how things would have been done without this excellent tool!

We hope you enjoy not only the technical aspects of the Conference but also the historic city of Chania.

Nikos Vitzilaios, H. Jin Kim, and Giuseppe Loianno

ICUAS'24 General Information

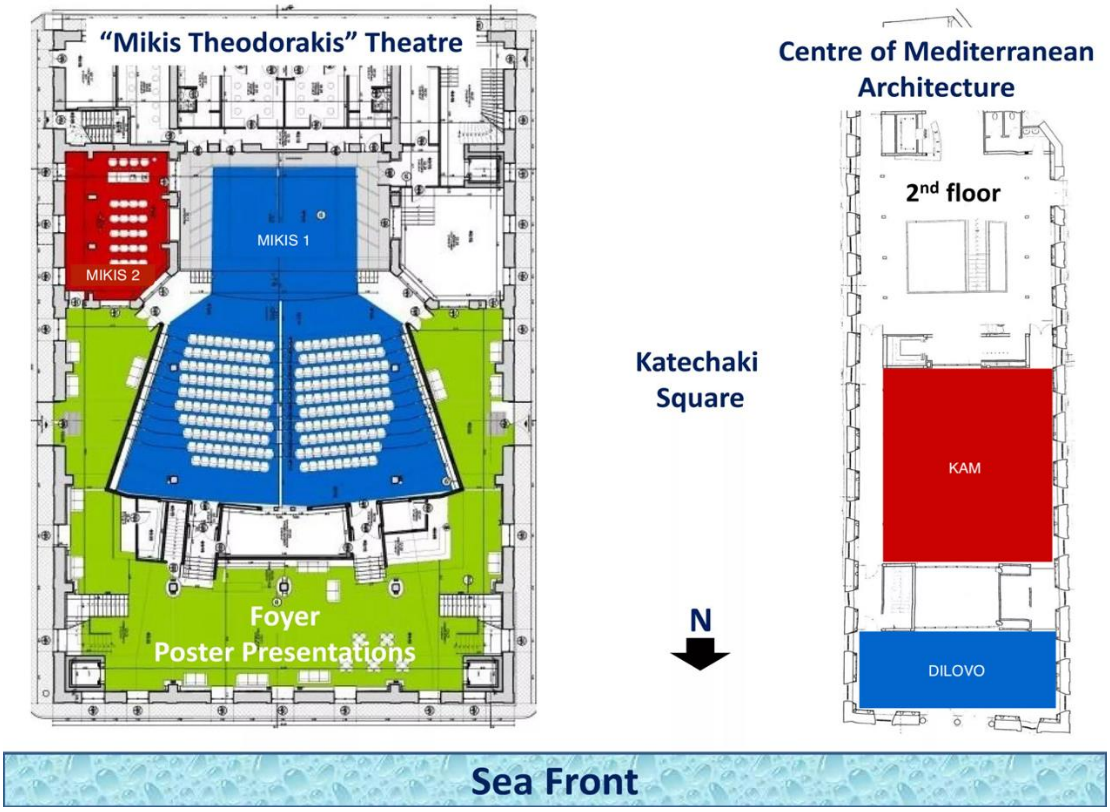
The Venues

The Conference venues are the "*Centre of Mediterranean Architecture* (KAM)" and the "*Mikis Theodorakis*" Theatre Hall, two historical and iconic buildings from the 15th century, which are in the Venetian harbor of the Old Town of Chania. The KAM building is also called the "*Great Shipyard*" (Megalo Arsenali).

Mikis Theodorakis Theatre

Centre of Mediterranean Architecture -KAM

The layout of the venues is shown below. The Conference will take place in both buildings, which are next to each other. ***MIKIS 1*** is the large Auditorium where all four Plenary talks will take place. Workshops / Tutorials and the parallel technical sessions will be in ***MIKIS 1***, ***MIKIS 2***, ***KAM*** and ***DILOVO***. Poster papers will be presented in the Foyer of the *Mikis Theodorakis* Theatre.



Traveling to Chania

Chania (also spelled Hania) is located on the northwest coast of the Greek island of Crete. Crete is about 160 km (99 mi) south of the Greek mainland.

Arriving by Air: The Chania Airport (IATA code: CHQ) is located on the peninsula of Akrotiri (or Souda), which is about 20 minutes (14 km) from the town of Chania. The Chania Airport operates domestic flights to and from Athens Airport, Thessaloniki Airport, and other airports in Greece. From April to early November, there are many direct charter flights to the Chania Airport from the UK, Germany, Italy, Scandinavia, and other European countries. More information may be found on the web site https://www.chania-airport.com/.

Traveling to Chania via Athens: The Athens International Airport "Eleftherios Venizelos" (IATA code: ATH) is serviced by all major airlines, offering direct non-stop flights from/to most of the major European cities, New York, Philadelphia, Montreal/Toronto, North Africa, Gulf States, South Africa, and easy connections to the rest of the world. ATH is also serviced by low-cost and/or charter airlines that offer attractive packages. More information: https://www.aia.gr/traveler/. There are several direct, non-stop flights between ATH and CHQ, serviced by Aegean Airlines, www.aegeanair.com, and Sky Express, https://skyexpress.gr.

Arriving by Sea: There is a ship/ferry from Piraeus (the port of Athens) to Souda Bay (Chania) every day. The route Piraeus to Chania is operated (all year round) by two companies: ANEK-Superfast and Minoan Lines. The trip duration is between 5 - 9 hours depending on the type of vessel.

Language and Currency

The official and national language of Greece is Greek, which is written in the Greek alphabet. In some tourist areas, you will also find street names and signs transliterated into the Latin script. Almost all Greeks speak English, French, German or Italian as a foreign language. Greece uses the Euro (EUR) as currency. Major debit and credit cards are accepted in cities and tourist areas in Greece. When shopping, however, you may get better deals with merchants with cash than debit or credit cards. You may withdraw Euros from all ATM machines. If you have a permanent non-EU residence and you plan to do shopping while in Greece, you may want to learn some tips and guidelines for tax free shopping.

Electricity, Plugs and Sockets

Electrical supply is 230 V, 50 Hz AC. Greece uses the standard European (round-pronged) plugs and power sockets. In technical terms, sockets are "type C" or "type F" (also known as "Schuko"), and they work with corresponding plugs (type C, E, F).

Visa Requirements

Citizens of some countries need an entry visa for Greece. For more information, check out the detailed visa information page.

CONFERENCE LOGISTICS

ICUAS'24 is a four-day event, starting with Workshops and Tutorials on Tuesday, June 4, followed by a three-day technical Conference on June 5-7. The Conference includes four Keynote Lectures. The meeting rooms in which all technical sessions will take place are ***MIKIS 1***, ***MIKIS 2***, ***KAM*** and ***DILOVO***. Poster papers will be presented in the Foyer of the *Mikis Theodorakis* Theatre. The Registration Desk is in the *Centre of Mediterranean Architecture* (KAM) building, on the main floor. Exhibit booths will also be on the main floor for maximum traffic.

Conference Registration

All Conference attendees must register by using the online registration when they upload the final version of their papers. This is the preferred option. Late and onsite registration is also available for non-authors who want to attend the Conference. It is not required to present a paper in the Conference program to register and to attend the Conference. All registered participants must check in at the Registration Desk to pick up their registration packages. Personal badges will be provided to all registered participants. Attendees must always wear their badges when attending any ICUAS'24 event (workshops, tutorials, technical sessions, and social functions). Conference details will be posted and updated daily in the registration area. To register, follow the steps:

- ✓ Go to https://controls.papercept.net
- ✓ Scroll down the list until you find ICUAS 2024 - Choose ICUAS 2024 (from the list of Conferences)
- ✓ Click on Register for ICUAS'24
- ✓ Login with your PIN and Password. *First time users must create a 'profile', to get a PIN and Password*.
- ✓ After you Log in, choose **Registree**.
- ✓ Follow the self-explained screens to register.

Alternatively, and especially if you have not authored a paper, you may register through www.icuas.com. The registration desk will be open during the following hours:

TUESDAY, JUNE 4:	***Workshop/Tutorial Registration only*** Note that morning registration is for Workshops and Tutorials only.	8:30 AM – 10:00 AM
	Conference Registration	3:00 PM – 5:00 PM
WEDNESDAY, JUNE 5:		8:00 AM – 4:00 PM
THURSDAY, JUNE 6:		8:30 AM – 2:30 PM
FRIDAY, JUNE 7:		8:30 AM – 11:00 AM

Onsite Conference registration policy & fees

Attendees can register for the Conference under the following registration categories/rates:

Attendee Status	**Registration Fee**
Full Regular Registration	$700
Student Registration	$360
Retiree Registration	$200
T1: Navigating the Ethical Skies: Community Best Practices for Drones and UAVs	$160
T2: Modeling and Control of Multirotor UAVs: *A Comprehensive Framework*	$160
T4: International methodologies for conducting Beyond Visual Line of Sight (BVLOS) flight operations with Remotely Piloted Aircraft Systems (RPAS)	$160
T3: Aerial Workers for Infrastructure and Asset Maintenance: The journey from "Lab" to "Real-World"	$240
T5: Heterogeneous Robotic System for Inspection and Intervention in GNSS-denied Environments	$160
Guest Registration (All Social Events)	$200
Extra Welcome Reception Ticket	$50
Extra Banquet Ticket	$100

Internet Access
All registered attendees will have complementary internet access.

Lunch for Registered Participants
Lunch will be served to registered Conference participants. Lunch tickets will be provided for Wednesday, Thursday and Friday, June 5 to 7.

Coffee Breaks with Snacks
There will be two coffee breaks per day for all registered participants, one in the morning and one in the afternoon.

Events and Receptions
The ICUAS'24 social agenda includes a *Welcome Reception* on Tuesday, June 4; *Banquet*, on Thursday, June 6.

ICUAS'24 Tutorials and Workshops

ICUAS'24 offers five pre-Conference Workshops/Tutorials addressing current and future topics in unmanned aircraft systems from experts in academia, national laboratories, and industry. Interested participants may find details on www.uasconferences.com, and they may use the online system for registration. Tutorials/Workshops will take place on Tuesday, June 4. Duration is either *Full-Day* (09:00 - 18:00) or *Half-Day* (09:00 - 13:00, or 14:00 – 18:00).

TUTORIALS / WORKSHOPS - Tuesday, June 4, 2024		
Location	**Time**	**Title**
MIKIS 1	Full-Day 9:00-18:00	*Aerial Workers for Infrastructure and Asset Maintenance: The Journey from "Lab" to "Real-World"*
MIKIS 2	Half-Day 9:00 – 13:00	*Navigating the Ethical Skies: Community Best Practices for Drones and UAVs*
KAM	Half-Day 9:00 – 13:00	*Modeling and Control of Multirotor UAVs: A Comprehensive Framework*
DILOVO	Half-Day 9:00 – 13:00	*International methodologies for conducting Beyond Visual Line of Sight (BVLOS) flight operations with Remotely Piloted Aircraft Systems (RPAS)*
MIKIS 2	Half-Day 14:00 – 18:00	*Heterogeneous Robotic System for Inspection and Intervention in GNSS-denied Environments*

ICUAS'24 Plenary Lectures

ICUAS'24 includes four Plenary Lectures given by leading authorities in their fields. We are proud to include them in the Technical Program. Plenary Lectures will be in the *MIKIS 1 Auditorium*. The schedule for the lectures is shown next.

PLENARY LECTURES		
Day	**Time**	**MIKIS 1 AUDITORIUM**
Wednesday June 5	09:00 – 10:00	***Vision-Based Robotic Perception: Are We There Yet?*** *Dr. Margarita Chli* *Vision for Robotics Lab, ETH Zurich & University of Cyprus*
Thursday June 6	09:00 - 10:00	***Biologically Inspired Drones*** *Dr. Dario Floreano* *Laboratory of Intelligent Systems, EPFL*
Thursday June 6	14:00 – 15:00	***Aerospace City in Torino: Project and Strategy*** *Dr. Fulvia Quagliotti* *President, Piemonte Aerospace Cluster*
Friday June 7	09:00 - 10:00	***Mapping Advanced Air Mobility to Mature Flight Operations*** *Dr. Chester Dolph* *Aeronautics Systems Engineering, NASA Langley Research Center*

ICUAS 2024 UAV Competition

The six finalist teams of the 2024 UAV Competition are shown below, along with the names of each team member. The teams will present their work on Thursday, June 6.

Team Name and Team Members	Institution	Country
AIRo Lab Zheng Tan and Wenyu Yang	*The Hong Kong Polytechnic University*	Hong Kong
ITUAV Onat Erdogmus and Levent Emre Nalici	*Istanbul Technical University*	Turkey
AVANT-UFMG Yan Figueiras Alves and Leonardo Reis Domingues Paes	*Universidade Federal de Minas Gerais (UFMG)*	Brazil
UNIST ASL Taewook Park and Myeonggeun Gu	*Ulsan National Institute of Science & Technology*	Republic of Korea
UAS-DTU Kush Garg and Somin Aggarwal	*Delhi Technological University*	India
AVADER AGH Remigiusz Mietla	*AGH University of Krakow*	Poland

ICUAS' 24 TECHNICAL PROGRAM AT A GLANCE

Workshops / Tutorials: Tuesday June 4

T1-MIKIS 2 09:00 – 13:00	T2 – KAM 09:00 – 13:00	T3 – MIKIS 1 09:00-18:00	T4 – DILOVO 09:00-13:00	T5 – MIKIS 2 14:00-18:00
Navigating the Ethical Skies: Community Best Practices for Drones and UAVs	*Modeling and Control of Multirotor UAVs: A Comprehensive Framework*	*Aerial Workers for Infrastructure and Asset Maintenance: The Journey from "Lab" to "Real-World"*	*International Methodologies for Conducting Beyond Visual Line of Sight (BVLOS) Flight Operations with Remotely Piloted Aircraft Systems (RPAS)*	*Heterogeneous Robotic System for Inspection and Intervention in GNSS-Denied Environments*

Technical Program: Wednesday, June 5

Coffee Breaks: **10:00 – 10:30**
16:00 – 16:30
Lunch: **12:30 – 14:00**

08:30-09:00
MIKIS 1
ICUAS 2024 Opening Ceremony

09:00-10:00
MIKIS 1 - Plenary Session
VISION-BASED ROBOTIC PERCEPTION: ARE WE THERE YET?

MIKIS 1	MIKIS 2	KAM	DILOVO
10:30-12:30 WeA1 *Multirotor Design and Control I*	10:30-12:30 WeA2 *UAS Applications I*	10:30-12:30 WeA3 *Path Planning I*	10:30-12:30 WeA4 *Autonomy*
14:00-16:00 WeB1 *Multirotor Design and Control II*	14:00-16:00 WeB2 *UAS Applications II*	14:00-16:00 WeB3 *Path Planning II*	14:00-16:00 WeB4 *Regulations*
16:30-18:30 WeC1 *Multirotor Design and Control III*	16:30-18:30 WeC2 *UAS Applications III*	16:30-18:30 WeC3 *Path Planning III*	16:30-18:30 WeC4 *Airspace Management/Control*

Technical Program: Thursday, June 6

Coffee Breaks: **10:00 – 10:30**
15:00 – 15:20
Lunch: **12:30 – 14:00**

09:00-10:00 **MIKIS 1 – Plenary Session** ***BIOLOGICALLY INSPIRED DRONES***			
MIKIS 1	**MIKIS 2**	**KAM**	**DILOVO**
10:30-12:30 ThA1 *Best Paper Award*	10:30-12:30 ThA2 *Aerial Robotic Manipulation*	10:30-12:30 ThA3 *Control Architectures*	10:30-12:30 ThA4 *Swarms I*
14:00-15:00 **MIKIS 1 – Plenary Session** ***AEROSPACE CITY IN TORINO: PROJECT AND STRATEGY***			
15:20-17:00 ThB1 *LATAM Best Paper Award*	15:20-17:00 ThB2 *Micro and Mini UAS*	15:20-17:00 ThB3 *Aerial Vehicles for Hazardous Applications: From Environmental Sensing to Operations in Extreme Environments*	10:30-12:30 ThB4 *UAS Reliability, Safety and Risk Assessment*
17:00-18:30 ThCo1 *UAV Competition*			

17:00-17:40 || MIKIS Foyer - ThPo1: Poster Session
17:50-18:30 || MIKIS Foyer - ThPo2: Poster Session

Technical Program: Friday, June 7

Coffee Breaks: **10:00 – 10:30**
16:00 – 16:30
Lunch: **12:30 – 14:00**

09:00-10:00 **MIKIS 1 - Plenary Session** ***MAPPING ADVANCED AIR MOBILITY TO MATURE FLIGHT OPERATIONS***			
MIKIS 1	**MIKIS 2**	**KAM**	**DILOVO**
10:30-12:30 FrA1 *Swarms II*	10:30-12:30 FrA2 *UAS Communications*	10:30-12:30 FrA3 *Perception and Cognition*	10:30-12:30 FrA4 *Navigation*
14:00-16:00 FrB1 *Aerial Robotics in Inspection and Maintenance Operations I*	14:00-16:00 FrB2 *Sensor Fusion*	14:00-16:00 FrB3 *UAS Applications IV*	14:00-16:00 FrB4 *Technology Challenges*
16:30-18:10 FrC1 *Aerial Robotics in Inspection and Maintenance Operations II*	16:30-18:10 FrC2 *Industrial Inspection and Maintenance with Aerial Manipulators*	16:30-18:10 FrC3 *Energy/Environment/Reliability*	16:30-18:10 FrC4 *Manned/Unmanned Aviation*

ICUAS ’24 Technical Sessions and Abstracts

Technical Program for Wednesday June 5

WeA1	MIKIS 1
Multirotor Design and Control I (Regular Session)	
Chair: Kim, H Jin	Seoul National University
Co-Chair: De Petris, Paolo	Norwegian University of Science and Technology

10:30-10:50	WeA1.1

Simple Interpolating Control with Non-Symmetric Input Constraints for a Tilt-Rotor UAV, pp. 1-7

Kaballo, Eliav	Ben-Gurion University of the Negev
Arogeti, Shai	Ben-Gurion University of the Negev

Contrary to the polytopic Interpolating Control (IC) approach, Simple Interpolating Control (SIC) applies to high-order systems and does not require online numerical optimization. SIC design approaches are based on linear matrix inequalities (LMIs) and are formulated for symmetrical design constraints. On the other hand, control input constraints are generally non-symmetric in nature. The purpose of this paper is to present how the quasi-non-symmetric constraint approach can be used to overcome this limitation in LMI-based SIC for high-order systems. An illustrative example of a tilt-rotor drone regulation problem demonstrates the robustness of the approach with respect to a naive conservative approach. Furthermore, it provides uncompromising performance against model predictive control (MPC) without the need to solve online optimization problems.

10:50-11:10	WeA1.2

Multirotor Lift Estimation under Battery Discharge and Blade Faults, pp. 8-14

Baldini, Alessandro	Università Politecnica Delle Marche
Felicetti, Riccardo	Università Politecnica Delle Marche
Ferracuti, Francesco	University Polytechnic of Marche
Freddi, Alessandro	Università Politecnica Delle Marche
Monteriù, Andrea	Università Politecnica Delle Marche
Scalella, Simone	Università Politecnica Delle Marche
Zhang, Yihang	Università Politecnica Delle Marche

During a flight, battery discharge leads to a reduction in output voltage, in line with the well-known nonlinear relation between battery voltage and its state of charge. This paper investigates the consequences of battery discharge on motor lift and, ultimately, on drone dynamics. The impact of battery voltage variation is then compared to that of blade faults in terms of magnitude, also highlighting similarities and differences. Furthermore, we derive a set of linear regressions and simple nonlinear equations from experimental data to describe the relationships between rotor speed, lift force, duty cycle, battery voltage, and propeller characteristics.

11:10-11:30	WeA1.3

Gain Scheduling Position Control for Fully-Actuated Morphing Multi-Rotor UAVs, pp. 15-22

Aboudorra, Youssef	University of Twente
Saini, Aaron	University of Twente
Franchi, Antonio	University of Twente

This work presents techniques for scheduling the position controller gains for a class of fully actuated morphing multi-rotor UAVs that use synchronized tilting to change their actuation capabilities. The feasible set of forces and torques that can be produced by the platform changes with the tilting angle, thus the tracking and disturbance rejection capabilities also change. To exploit the platform limits, two methods are proposed for gain scheduling using a simplified example, then one method is tested in simulation with an omnidirectional morphing multi-rotor (OmniMorph). The simulation results show that the developed techniques achieve consistent position tracking performance along the range of tilting angles when rejecting step disturbance forces of values close to the maximum force capabilities. The proposed methods offer a trade-off between simplicity and accuracy, that could be potentially applied for any multi-rotor with synchronized tilting capabilities. A video summary can be found in: https://youtu.be/kH-rrO8gWeU

11:30-11:50	WeA1.4

Online Residual Learning Using Interpretable Reservoir Computing for Quadrotor Control, pp. 23-30

Gu, Weibin	Politecnico Di Torino
Rizzo, Alessandro	Politecnico Di Torino

Quadrotors, valued for their mobility and cost-effectiveness, have found widespread use in applications such as aerial photography and infrastructure inspection. However, their complex and nonlinear dynamics make them sensitive to uncertainties. In dynamic scenarios with online data but little-to-no prior knowledge of these unknowns, data-driven approaches show promise in both system identification and controller design. Nonetheless, the black-box nature of deep learning poses challenges for trust and generalizability. In this paper, we introduce a novel tracking controller featuring an online learning module for quadrotor residual dynamics. This module, implemented using deep Echo State Network (ESN), enhances adaptability to unforeseen scenarios, thereby extending the applicability of the controller to a broader range of situations. Furthermore, we employ post-hoc interpretation techniques tailored for the ESN to improve trustworthiness. This is achieved through dynamic system analysis and visualization of network predictions. Simulation results demonstrate the effective tracking of a figure-8 trajectory with online learning compensating for various non-parametric uncertainties, which showcases the potential of the proposed approach and establishes a foundation for the real-world testing in future.

11:50-12:10	WeA1.5

Design, Modeling, Control and Experimental Evaluation of Flexy: A Novel Compliant Quadrotor, pp. 31-38

De Petris, Paolo	Norwegian University of Science and Technology
Nissov, Morten Christian	Norwegian University of Science and Technology
Harms, Marvin Chayton	ETH Zürich
Alexis, Kostas	NTNU

This work presents the design, control and experimental validation of a novel quadrotor that embeds elastic joints in its arms thus paving the road towards the further utilization of soft, squeezable, and resiliently collision-tolerant aerial robots. The system design is presented in detail and the properties of the elastic joints are identified. Furthermore, the effects of soft joints on the motion dynamics are outlined, while a Sliding Mode Controller is derived based on a rigid vehicle model. Exploiting the robust control performance of such a controller, accurate trajectory tracking within agile maneuvering is experimentally achieved for the proposed flexible aerial robot. Additional experiments also assess the collision- tolerance of the robot in forcible impacts and the capacity of the closed-loop controller to return the vehicle safely back to hover. Finally, the ability of the system to passively morph its shape and thus squeeze to fit through openings that are smaller than its nominal dimension is demonstrated.

12:10-12:30	WeA1.6

Saturated RISE Control for Considering Rotor Thrust Saturation of Fully Actuated Multirotor, pp. 39-44

Lee, Dongjae	Seoul National University
Kim, H Jin	Seoul National University

This work proposes a saturated robust controller for a fully actuated multirotor that takes disturbance rejection and rotor thrust saturation into account. A disturbance rejection controller is required to prevent performance degradation in the presence of parametric uncertainty and external disturbance. Furthermore, rotor saturation should be properly addressed in a controller to avoid performance degradation or even instability due to a gap between the commanded input and the actual input during saturation. To address these issues, we present a modified saturated RISE (Robust Integral of the Sign of the Error) control method. The proposed modified saturated RISE controller is developed for expansion to a system with a non-diagonal, state-dependent input matrix. Next, we present reformulation of the system dynamics of a fully actuated multirotor and apply the control law to the system. The proposed method is validated in simulation where the proposed controller outperforms the existing one thanks to the capability of handling the input matrix.

WeA2	**MIKIS 2**
UAS Applications I (Regular Session)	
Chair: Tsourdos, Antonios	Cranfield University
Co-Chair: Fasano, Giancarmine	University of Naples "Federico II"

10:30-10:50	WeA2.1

Collaborative Aerial 3D Printing: Leveraging UAV Flexibility and Mesh Decomposition for Aerial Swarm-Based Construction, pp. 45-52

Stamatopoulos, Marios-Nektarios	Luleå University of Technology
Banerjee, Avijit	Luleå University of Technology
Nikolakopoulos, George	Luleå University of Technology

The article introduces a novel approach to foster collaborative aerial 3D printing by leveraging the dexterous flexibility of multiple UAVs working in tandem towards autonomous construction. This cooperative operation effectively overcomes payload limitations through synchronized deployment. Nevertheless, the transformation of UAVs into aerial construction agents poses a pivotal challenge, demanding efficient coordination of task planning and effective execution among multiple collaboratively working UAVs. In pursuit of addressing this challenge, the proposed innovative framework introduces a novel chunk-decomposition strategy supported by a reactive task assignment mechanism, dynamically allocating additive manufacturing tasks based on a dependency graph derived from decomposed chunks. Furthermore, the framework promotes parallelization by minimizing interdependencies, thereby reducing the overall makespan. It also incorporates conflict resolution among UAVs during the assignment process by employing probabilistic fitness scores and penalizing the probability of conflicts. Conflicts that emerge during printing execution are addressed in a decentralized manner through trajectory sharing among UAVs. This entails dynamically determining one UAV suspending its movement until conflicts are resolved. The proposed framework's effectiveness is evaluated through a GAZEBO-based simulation setup, showcasing its potential in deploying multiple UAVs for the simultaneous printing of large-scale 3D structures.

10:50-11:10	WeA2.2

Experimental Results of Utilizing the 3GPP LTE Positioning Protocol for Providing RTK Reference Data to High-Accuracy UAV Operations, pp. 53-60

Jepsen, Jes Hundevadt	University of Southern Denmark
Gunnarsson, Fredrik	Ericsson Research
Wen, Rongrong	Ericsson AB
Wase, Jonathan	Ericsson
Jensen, Kjeld	University of Southern Denmark

This paper presents experimental results of utilizing the 3GPP standardized RTK Observation State Representation (OSR). The work investigates the 3GPP LTE Positioning Protocol (LPP)'s applicability for enabling reliable and accurate global localization during UAV operations. The experiments are conducted with a UAV connected to a 5G network, utilizing a cellular connection for 1) directly receiving RTCM data via an open source 3GPP LPP client developed by the authors, and 2) establishing a C2 link to the Ground Control Station.

A 24-hour measurement with the UAV remaining at a static position has been conducted. The results indicate a reliable performance with no loss of RTK GNSS fixed solution. Furthermore, two similar static experiments have been conducted with: 1) receiving RTCM data via an NTRIP client connected to an RTK reference network service, indicating no difference in the two approaches' performance when compared, and 2) with no RTCM data provided, to compare the baseline performance of the UAV's GNSS.

The operational reliability, meaning its performance during operational conditions when receiving RTCM data via LPP, has been investigated with UAV flights. The results consist of measurements from 1) the UAV's RTK GNSS to investigate its performance during flight, and 2) the 5G network to investigate its performance in different altitudes and potentially correlate loss of RTK GNSS fixed solution due to the network connectivity. Seventeen flight experiments have been conducted, resulting in a total flight time of 3 hours and 19 minutes distributed over 32.06 kilometers. No loss of RTK GNSS fixed solution was observed, showing stable operational reliability in the area where the flight tests were conducted.

11:10-11:30	WeA2.3

Disaster Area Coverage Optimisation Using Reinforcement Learning, pp. 61-67

Gruffeille, Ciaran	Cranfield University
Perrusquía, Adolfo	Cranfield University
Tsourdos, Antonios	Cranfield University
Guo, Weisi	Cranfield University

Search and rescue applications using unmanned aerial vehicles (UAVs) also known as drones are becoming a research topic of interest to industry and academia due to its high impact on the ecosystem and people. Exploration of the disaster area is a crucial element in search and rescue to identify the zones that require immediate assistance or with high hazard probability. This paper aims to contribute to the coverage optimisation of a disaster area using drones. We focus on a flood disaster scenario as case of study. The proposed approach consists in two main parts: i) a Siamese-net is used to identify flooded buildings in satellite images, and ii) the points of interest are converted into a suitable maze environment that subsequently is used by any reinforcement learning (RL) architecture for area coverage optimisation. Here, the goal of the RL architecture is to ensure that the complete environment is covered by the drone by optimizing time and previously visited zones. Experiments are conducted to show the benefits and challenges of the current approach.

11:30-11:50	WeA2.4

High-Resolution 5G Active Antenna Beam Pattern Measurement Using UAVs, pp. 68-75

Dasari, Mohan	University of Luxembourg
Kumar, Sumit Kumar	University of Luxembourg
Habibi, Hamed	Nterdisci Plinary Centre for Security, Reliability and Trust, U
Querol, Jorge	University of Luxembourg
Chatzinotas, Symeon	University of Luxembourg
Voos, Holger	University of Luxembourg

This paper presents a measurement methodology for obtaining a high-resolution beam pattern of 5G active antenna systems (AASs) using Unmanned Aerial Vehicles (UAVs). Beam pattern measurements are typically conducted in an anechoic chamber by placing the active antenna at the center and radiation pattern is measured at various angles. This approach is limited by the spatial constraints of the chamber and is time-consuming for obtaining high-resolution measurements. To address this problem, UAVs equipped with measurement sensors are proposed to fly around the antenna and do the measurement campaign. The beam pattern measurement campaign problem is formulated into a UAV path planning problem. Horizontal circular arcs at various elevation angles are defined on a sphere centered at the antenna and connected at their ends alternatively to define a reference path and transcribe it into a reference trajectory for the UAV. A chattering-free super-twisting controller is designed to accurately track this trajectory against unknown matched disturbances and model uncertainties. The proposed methodology is validated by an indoor experiment with a horn antenna set up to operate in the frequency range of a 5G AAS and create a stationary beam. A universal software radio peripheral is mounted on a UAV and programmed to measure the received signal strength indicator in real time and a high-resolution beam pattern is satisfactorily captured.

11:50-12:10	WeA2.5

VESSELimg: A Large UAV-Based Vessel Image Dataset for Port Surveillance, pp. 76-83

Rubi, Bartomeu	Eurecat
Cacace, Jonathan	Universita' Di Napoli Federico II
Javier, Rodriguez	Eurecat
Rafa, Company	Fundación Valenciaport
Mark, Tanner	Fundación Valenciaport
Roberto, Arzo	Fundación Valenciaport
Cayero, Julian Cayero	Eurecat

In the domain of maritime security and safety, the surveillance and monitoring of vessels in ports are crucial for safeguarding against potential threats and ensuring the overall integrity of port operations. Current port surveillance methods, including radar systems, CCTV networks, and AIS, exhibit limitations, necessitating innovative solutions. The integration of drone-captured imagery holds promise, particularly for detecting non-cooperative vessels that may evade traditional surveillance methods.

This paper presents VESSELimg dataset, a meticulously gathered and annotated collection of drone-captured images within port environments. This dataset serves as a benchmark for training and validating deep learning models, specifically tailored for automatic vessel detection, covering diverse vessel types. The implementation of a YOLO-based deep learning model for real-time inference demonstrates the practical applicability of the dataset, underscoring its potential for enhancing security and safety measures in port environments.

12:10-12:30	WeA2.6

Cooperation-Aided Accurate UAV-Based LiDAR Mapping: Experimental Assessment, pp. 84-91

Causa, Flavia	University of Naples Federico II
Opromolla, Roberto	University of Naples Federico II
Fasano, Giancarmine	University of Naples "Federico II"

This paper presents results of an experimental activity conducted to prove the feasibility of using cooperation among Unmanned Aerial Vehicles to improve the geolocalization accuracy in Light Detection and Ranging (LiDAR)-based mapping applications. A chief-deputies architecture is considered, where the navigation state of the chief platform (which is embarking the LiDAR payload) is estimated by fusing measurements of its onboard Inertial Measurement Unit (IMU) and Global Navigation Satellite System (GNSS) receiver, with IMU-independent attitude measurements obtained by exploiting cooperation with the deputy platforms. Specifically, the chief attitude is computed by tightly integrating visual- and Carrier-phase Differential GNSS (CDGNSS) measurements of the chief-deputies directions in body and local coordinates, respectively, in the correction step of an extended Kalman filter. An experimental flight test has been conducted in a powerline mapping scenario to assess the performance of this cooperative technique in providing accurate geolocalized data. The experimental setup includes the following items: one customized DJI M300 platform (acting as chief) equipped with a Livox MID-40 LiDAR (mapping payload) and a fisheye camera (cooperative visual sensor); and two customized DJI M100 platforms acting as deputies. The three platforms are also equipped with GNSS receivers with raw data capability to enable CDGNSS processing. Results demonstrate an ability of reconstructing powerlines with a 0.42m Root Mean Square dispersion of the geolocalized points.

WeA3	**KAM**
Path Planning I (Regular Session)	
Chair: Ollero, Anibal	Universidad De Sevilla - Q-4118001-I
Co-Chair: Bronz, Murat	ENAC

10:30-10:50	WeA3.1

FollowThePathNet: UAVs Use Neural Networks to Follow Paths in GPS-Denied Environments, pp. 92-98

Raichl, Petr	Brno University of Technology
Janoušek, Jiří	Brno University of Technology, the Faculty of Electrical Engineering
Marcon, Petr	Brno University of Technology

Navigating complex pathways autonomously poses a significant challenge for Unmanned Aerial Vehicles (UAVs). To address this issue, we developed a robust convolutional neural network (CNN) enabling UAVs to follow specific paths, such as trails, rural, and cycling ones, using real-time camera data. Our CNN model interprets the visual data to estimate the UAV's position relative to the path, enabling path following without human intervention. This article details the methodology employed in training our neural network, including the data collection, architecture of the model, and parameters. Additionally, we describe integrating the hardware and software components used in the implementation. We conducted real- world tests to evaluate the effectiveness of our approach. These tests confirmed the UAVs' capability to follow the designated paths, demonstrating the practical applicability and reliability of the system. The results and their implications are discussed thoroughly.

10:50-11:10	WeA3.2

Route Optimization of Vessel-UAV Tandem Systems for Offshore Wind Farm Inspections, pp. 99-106

Fontenla Carrera, Gabriel	University of Vigo
Aldao Pensado, Enrique	University of Vigo
Veiga-López, Fernando	University of Vigo
Gonzalez Jorge, Higinio	University of Vigo

Offshore wind turbine inspections using autonomous Unmanned Aerial Vehicles (UAVs) allow for better data acquisition than those carried out by traditional methods. Besides, they are faster, safer, and more economical by reducing the number of crew members exposed to dangerous environments. This article proposes a vessel-UAV tandem system in which the routes of both vehicles are optimized in three steps. First, the number of points where the vessel must be placed to cover all the turbines is minimized and the optimal positions where it must remain are sought. Second, the routes that the UAV must follow to reach all the wind turbines from each position of the vessel are calculated, including battery changes. Finally, the vessel route will be optimized based on the number of days needed to cover all the wind farm and the possibility, or not, to spend the nights at sea.

11:10-11:30	WeA3.3

A Velocity qLMPC Algorithm for Path-Following with Obstacle Avoidance for Fixed-Wing UAVs, pp. 107-112

Rezk, Ahmed Samir Said Metwalli	Hamburg University of Technology
Martínez Calderón, Horacio	IAV GmbH
Werner, Herbert	Hamburg University of Technology
Herrmann, Benjamin	Hamburg University of Technology
Rieck, Leif	Hamburg University of Technology
Thielecke, Frank	Hamburg University of Technology

This paper tackles the problem of path-following control for fixed-wing UAVs, while accounting for wind disturbances and hindering obstacles. We introduce a novel predictive algorithm based on a qLPV model representation of the 3D kinematics of the fixed-wing aircraft. This approach allows us to utilize efficient Quadratic Programming (QP) solvers to find efficient and fast solutions to the Optimal Control Problem (OCP), typically within milliseconds. Additionally, it facilitates the incorporation of appropriate constraints aligned with

the aircraft dynamics and obstacle constraints after further processing. In this paper, we demonstrate how the nonlinear obstacle constraints can also be represented in a qLPV form, making it feasible to handle them within our framework. Moreover, stability conditions can be directly derived based on the qLPV representation. The algorithm's effectiveness is demonstrated on an aerobatic unmanned aircraft with a Successive-Loop-Closure (SLC) based attitude and stabilization controller. The evaluation is conducted across two scenarios previously used in experimental flights with the same aircraft. Each scenario involves nine waypoints, obstructive obstacles, and wind disturbances. The simulations begin with the kinematic model and are subsequently extended to a high-fidelity model of the UAV, resulting in successful path-following and obstacle avoidance with relatively low computational times.

11:30-11:50	WeA3.4

Constrained PSO-Splines Trajectory Generation for an Indoor Nanodrone, pp. 113-120

Marguet, Vincent	Universite Grenoble Alpes
Dinh, Cong Khanh	Univ. Grenoble Alpes, Grenoble INP, LCIS
Prodan, Ionela	Grenoble INP, Univ. Grenoble Alpes
Stoican, Florin	Politehnica University of Bucharest

The trajectory generation problem is still challenging as it involves determining a smooth and feasible path considering convoluted constraints. This paper builds upon the strengths of fast computation of PSO (Particle Swarm Optimization) and the B-splines properties to solve an optimization problem for trajectory planning. The precomputed trajectory of an indoor quadcopter is parameterized by B-splines functions allowing to enforce operation constraints (i.e., position, velocity, angles, thrust, angular velocity, waypoint passing) while minimizing the input effort. Simulation and experimental testing with a nanodrone validate our approach.

11:50-12:10	WeA3.5

FLighthouse: Python Development Framework for Multi-Agent Guidance and Path Planning for Unmanned Aerial Systems, pp. 121-128

del Ser, Adrian	ENAC
Bilgin, Zeynep	Technical University of Munich
Yavrucuk, Ilkay	Middle East Technical University
Bronz, Murat	ENAC

This paper introduces FLighthouse, an open-source python framework designed for development and testing of multi-agent guidance and path planning algorithms. FLighthouse is composed of three key components: SceneBuilder for intuitive 2D use case creation, guidance algorithms integration, and an execution module with visualization and post processing tools. The proposed framework can be used with a wide range of guidance and path planning algorithms and allows for execution and comparison of metrics for different guidance approaches. The framework supports execution in both simulation and real flights. The visualization tool is equipped with analysis tools for detailed interpretation of results. It can also provide real-time feedback for immediate assessment. The effectiveness of the proposed framework is demonstrated with three different example scenarios. Example cases demonstrate comprehensive use of the features and highlight the interoperability and compatibility of the framework. FLighthouse's minimal system requirements, necessitating only Python 3 and a few additional libraries, facilitate installation and ensure compatibility across a broad range of systems, enabling rapid development and testing of novel guidance methods.

12:10-12:30	WeA3.6

Hybrid Flapping and Gliding Flight for Robot Bird Using Closed-Loop Nonlinear Optimal Control: Indoors Experimentation, pp. 129-135

Rafee Nekoo, Saeed	Escuela Técnica Superior De Ingeniería, Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla - Q-4118001-I

Hybrid flight of flapping-wing flying robots (FWFRs) is one of the advantages of flapping-wing mechanisms for thrust and lift generation of aerial platforms. Hybrid flight refers to the capacity of switching between flapping and gliding modes. The source of thrust and lift generation is the flapping state; however, in the condition of favorable wind and sufficient height from the ground, gliding flight can be achieved. The gliding phase, flight without a main flapping motor offers several important features: requiring less energy per covered horizontal distance, and flight without oscillation. The focus of this work is to investigate the reduction of oscillation in indoor flights where the flight zone is a closed limited space. In point-to-point control of the robot bird, the last meter approach to the final desired point, ideally demands less oscillations. The implementation of the closed-loop nonlinear control on the FWFR is studied; the controller is so-called the state-dependent Riccati equation (SDRE). The experiments showed successful switching between flapping and gliding controllers in the indoor tests. The lack of wind in an indoor environment increases the difficulty of gliding and the results showed a significant decrease in height with an increase in the gliding distance.

WeA4	**DILOVO**
Autonomy (Regular Session)	
Chair: Costello, Donald	USNA
Co-Chair: Cella, Marco	AIT - Austrian Institute of Technology

10:30-10:50	WeA4.1

Probabilistic Object Tracking Using Quantified Camera Uncertainty Parameters in a Binocular System, pp. 136-143

Civetta, Chris	USNA
Costello, Donald	USNA
Kutzer, Michael	United States Naval Academy

As the Navy becomes increasingly autonomous and attempts to lower its radio frequency (RF) signature, the need for improved optically driven systems increases. Research on a binocular camera system's ability to track an object in three- dimensional (3D) space using statistical uncertainty supports this effort. By leveraging ground truth data provided by USNA's Vision Integration In Polymanual and Experimental Robotics (VIPER) lab, the binocular system's uncertainty parameters are experimentally estimated, and the overall uncertainty of the system's ability to track an object is approximated. Unlike traditional tracking methods, this process produces a probability "cloud" around the object of interest, providing confidence intervals around the target of interest. This research supports sensor-based autonomy in two ways: (1) enabling tracking systems to use probabilistic information to establish confidence regions for risk assessment and decision making; (2) provide tracking uncertainty in automated image labeling to improve the training efficacy of neural networks.

10:50-11:10	WeA4.2

Improved Learning in Multi-Agent Pursuer-Evader UAV Scenarios Via Mechanism Design and Deep Reinforcement Learning, pp. 144-151

Cabral, Kleber	Queen's University
Delamer, Jean-Alexis	St. Francis Xavier University
Rabbath, Camille Alain	DRDC
Lechevin, Nicolas	Defence Research & Development Canada
Williams, Craig	Royal Military College of Canada
Givigi, Sidney	Queen's University

Cooperation is a challenging task as balancing the desired outcome for a group of autonomous agents while they perceive/act based on their own point of view poses an interesting research question. Many approaches have been proposed for dealing with this issue using Deep Reinforcement Learning (DRL) solutions, where the agents learn how to weigh their decisions based on the group's interests. In such solutions, the design of the reward functions for multi-agent DRL problems is an area that is still open to be explored given the complexity of the analysis and the environment-agents relationships. In this work, we propose the application of the Vickrey-Clarke-Groves mechanism design principles to derive reward functions to be applied during the training of autonomous agents in a cooperative multiple pursuer-evader game scenario. Such economic theory is very promising given the capability of incentivizing and penalizing agent's behaviour given the impact of their actions on the whole group. Our results show that the proposed reward scheme causes the agents to learn faster and to be more effective in achieving solutions to the pursuer-evader problem when compared to DRL solutions using traditional reward functions.

11:10-11:30	WeA4.3

Embedded Real-Time Model Predictive Flight Control for Energy-Efficient UAS, pp. 152-159

Khamvilai, Thanakorn	ControlX, Inc
Huang, Mike	ControlX, Inc
Pakmehr, Mehrdad	CEO, ControlX, Inc

Model Predictive Control (MPC) is a powerful control framework that recurrently provides a control signal to optimally control a system. However, in the application of an Unmanned Aerial System (UAS) with a multirotor configuration, MPC is often used more as a high-level guidance system than as a low-level flight controller due to the extensive computation required to solve for an optimal solution given the UAS's relatively fast dynamics. As a result, the eventual performance of the UAS is degraded from the optimal measure predicted by the MPC. This paper addresses this challenge by formulating the MPC problem for both position and attitude controls, specifically for UAS with a multi-rotor configuration, and developing an optimization solver tailored to the problem, enabling the framework to be executed in real-time on a commercial-off-the-shelf embedded hardware platform. Experimental flight tests have been conducted, and the resulting performance is compared with that of the baseline flight control in terms of energy consumption.

11:30-11:50	WeA4.4

A Comprehensive Framework for UAV-Based Autonomous Target Finding in Environments with Limited Global Navigation Satellite Systems and Reduced Visibility, pp. 160-167

Boiteau, Sebastien	Queensland University of Technology
Vanegas Alvarez, Fernando	Queensland University of Technology
Gonzalez, Luis Felipe	Queensland University of Technology (QUT)/ QUT Centre for Robotics

This paper presents a comprehensive framework for Unmanned Aerial Vehicles (UAVs) autonomous navigation in cluttered environments with no Global Navigation Satellite System (GNSS) and low visibility. Partially Observable Markov Decision Process (POMDP) is used to model decision making under uncertainty. The POMDP formulation was designed to allow a UAV to achieve a Search and Rescue (SAR) mission in an environment comprised of a restricted flying area, obstacles, no GNSS, and visual obscurant in the form of smoke. The mission objective is to explore the environment while avoiding obstacles to detect a human being using a thermal camera. A more realistic observation of the target's detection was modelled within the POMDP. This includes enhancing the state and observation vectors to include the characteristics of a bounding box generated by a deep-learning classifier. The framework also integrates a 2D LIDAR/Inertial odometry using the Hector SLAM package for pose estimation. It is tested in a simulation using Gazebo, Robotic Operating System (ROS), and the PX4 Firmware. Experiments conducted in the simulated SAR scenario tested the system under varying levels of pose estimation uncertainty, with an unknown target position. The experiments with the new observation function and low uncertainty pose estimation were a success. However, the framework was limited with higher uncertainty from the LIDAR/Inertial odometry, demonstrating the importance of a reliable pose estimation.

11:50-12:10	WeA4.5

A Robust LiDAR-Based Indoor Exploration Framework for UAVs in Uncooperative Environments, pp. 168-176

Bolz, Wolfgang	Austrian Institute of Technology
Cella, Marco	Austrian Institute of Technology
Maikisch, Noah	Austrian Institute of Technology

Vultaggio, Francesco	Austrian Institute of Technology
d'Apolito, Francesco	Austrian Institute of Technology
Bruckmüller, Felix	Austrian Institute of Technology
Sulzbachner, Christoph	Austrian Institute of Technology
Fanta-Jende, Phillipp	Austrian Institute of Technology

This paper introduces a robust framework for autonomous exploration using UAVs in uncooperative indoor environments, i.e. destroyed, unknown, and with limited visibility. The proposed system integrates a LiDAR-based Simultaneous Localization and Mapping (SLAM) algorithm, a Euclidian/Truncated Signed Distance Field (E/TSDF) mapping approach, a frontier-based exploration logic, a B-Spline motion planner, and a parallel Collision Avoidance (CA) module to ensure safe and efficient navigation through unexplored areas in real-time. Successful validation in simulated environments demonstrates the system's robustness in handling real-world issues such as odometry uncertainty, depleted point clouds, and intermittent networking in distributed setups.

12:10-12:30	WeA4.6

Human-Centric Aware UAV Trajectory Planning in Search and Rescue Missions Employing Multi-Objective Reinforcement Learning with AHP and Similarity-Based Experience Replay, pp. 177-184

Ramezani, Mahya	University of Luxembourg
Amiri Atashgah, M.A.	University of Tehran
Sanchez-Lopez, Jose-Luis	SnT, University of Luxembourg
Voos, Holger	University of Luxembourg

The integration of Unmanned Aerial Vehicles (UAVs) into Search and Rescue (SAR) missions presents a promising avenue for enhancing operational efficiency and effectiveness. However, the success of these missions is not solely dependent on the technical capabilities of the drones but also on their acceptance and interaction with humans on the ground. This paper explores the effect of human-centric factor in UAV trajectory planning for SAR missions. We introduce a novel approach based on the reinforcement learning augmented with Analytic Hierarchy Process and novel similarity-based experience replay to optimize UAV trajectories, balancing operational objectives with human comfort and safety considerations. Additionally, through a comprehensive survey, we investigate the impact of gender cues and anthropomorphism in UAV design on public acceptance and trust, revealing significant implications for drone interaction strategies in SAR. Our contributions include (1) a reinforcement learning framework for UAV trajectory planning that dynamically integrates multi-objective considerations, (2) an analysis of human perceptions towards gendered and anthropomorphized drones in SAR contexts, and (3) the application of similarity-based experience replay for enhanced learning efficiency in complex SAR scenarios. The findings offer valuable insights into designing UAV systems that are not only technically proficient but also aligned with human-centric values.

WeB1	**MIKIS 1**
Multirotor Design and Control II (Regular Session)	
Chair: Akbari, Babak	Queen's University
Co-Chair: Liarokapis, Minas	The University of Auckland

14:00-14:20	WeB1.1

A Computationally Efficient Learning-Based Model Predictive Control for Multirotors under Aerodynamic Disturbances, pp. 185-192

Akbari, Babak	Queen's University
Greeff, Melissa	Queen's University

Neglecting complex aerodynamic effects hinders high-speed yet high-precision multirotor autonomy. In this paper, we present a computationally efficient learning-based model predictive controller that simultaneously optimizes a trajectory that can be tracked within the physical limits (on thrust and orientation) of the multirotor system despite unknown aerodynamic forces and adapts the control input. To do this, we leverage the well-known differential flatness property of multirotors, which allows us to transform the nonlinear dynamics into a linear model. The main limitation of current flatness-based planning and control approaches is that they often neglect dynamic feasibility. This is because these constraints are nonlinear because of the mapping between the input, i.e., multirotor thrust, and the flat state. In our approach, we learn a novel representation of the drag forces by learning the mapping from the flat state to the multirotor thrust vector (in a world frame) as a Gaussian Process (GP). Our proposed approach leverages the properties of GPs to develop a convex optimal controller that can be iteratively solved as a second-order cone program (SOCP). In simulation experiments, our proposed approach outperforms related model predictive controllers that do not account for aerodynamic effects on trajectory feasibility, leading to a reduction of up to 55% in absolute tracking error.

14:20-14:40	WeB1.2

System Identification for Fully-Actuated UAV Control Allocation, pp. 193-200

Spaans, Jos	University of Auckland
Gilbert, Sam	University of Auckland
Stol, Karl	University of Auckland
Al-zubaidi, Salim	University of Auckland

Control allocation in multirotor unmanned aerial vehicles (UAVs) converts control signals to commands for individual actuators. Errors may be introduced into the system via inaccurate or insufficient control allocation due to aerodynamic effects, saturation, or hardware asymmetries. This paper presents a methodology to experimentally estimate such control allocation errors for a UAV in free-flight using motion-capture. The methodology is tested with a fully actuated octocopter, and steady-state allocation errors are identified and investigated. A generalized experimental approach to deriving control allocation is then introduced. The approach uses system identification to model-fit the control allocator of a UAV from free-flight data. The approach was tested and reduced allocation error by

22% for the fully actuated octocopter. Finally, a matrix representation for comparing control allocators is introduced and used to identify allocation error causes.

14:40-15:00	WeB1.3

Adaptive IBVS Based Planar Non-Holonomic Target Tracking for Quadrotors, pp. 201-208

Kumar, Yogesh	IIIT Delhi
Basu Roy, Sayan	Indraprastha Institute of Information Technology, Delhi (IIITD)
Baliyarasimhuni, Sujit, P	IISER Bhopal

This paper presents an adaptive image-based visual servoing (IBVS) technique for a quadrotor to track a moving planar non-holonomic target with unknown constant body fixed linear velocity and arbitrary angular motion. We propose a novel target velocity estimator augmented kinematic controller based on appropriately derived feature dynamics in a virtual image plane. Through a comprehensive theoretical analysis based on the Lyapunov direct method, we prove the convergence of feature tracking errors to zero for translational kinematics and to an ultimate bound for rotational kinematics despite the unknown target motion and parameter uncertainty in desired feature depth. The theoretical claims are validated using model-in-the-loop and software-in-the-loop (SITL) simulations.

15:00-15:20	WeB1.4

Fault Detection and Tolerant Control for Aero2 2DOF Two-Rotor Helicopter, pp. 209-215

Dandago, Khalid Kabir	University of Manchester
Zhang, Long	University of Manchester
Pan, Wei	The University of Manchester

Stability and satisfactory performance are key control requirements for any Unmanned Aerial Vehicle (UAV) application. Although conventional control systems for UAVs are designed to ensure flight stability and safe operation while achieving a desired task, a UAV may develop different types of flight faults that could lead to degradation in performance or, worse, instability. Unsatisfactory performance or instability of a UAV poses threats to lives, properties, and the flying environment. Therefore, it is crucial to design a system that can detect the occurrence of faults, identify the location at which the fault occurs, determine the severity of the fault, and subsequently use this information to accommodate the fault so that the vehicle can continue to operate satisfactorily. Even though performance analysis of faults is crucial in selecting the best strategies for fault detection and tolerance, little has been done in this regard, especially with real systems. Therefore, this paper analyzed the performance of a 2-degree-of-freedom (2DOF) bi-rotor helicopter's control system in the presence of various actuator faults. Results from different faulty conditions indicate that faults degrade the performance of a conventional control system on UAVs and introduce vibrations into the system. These findings are more apparent when a fault leads to asymmetry or imbalance of the system. However, further experiments have shown that proper fault diagnosis and accommodation methods could help maintain satisfactory performance of the system in the presence of faults.

15:20-15:40	WeB1.5

AI-Based Adaptive Nonlinear MPC for Quadrotors, pp. 216-223

Zhang, Luoqi	National University of Singapore
Huang, Sunan	National University of Singapore
Xiang, Cheng	National University of Singapore
Teo, S H	DSO National Lab
Srigrarom, Sutthiphong	National University of Singapore
Leong, Wai Lun	National University of Singapore

The UAV flight control tasks, especially their stabilities under large disturbances, are always complex and troublesome. In many application environments, drones are subject to both external interference and internal structural changes, which greatly affects the tracking accuracy. In this paper, an AIbased nonlinear control strategy was presented for unmanned aerial vehicles to achieve accurate tracking tasks. The basic idea is to combine neural network learning with traditional nonlinear model predictive control (NMPC). Moreover, some adaptive control algorithms are adopted for better robustness. First, existing MPC with L1 adaptive control is adopted as main controller for rejecting external disturbances. Second, considering path tracking performance, model reference adaptive control is added to the control policy to compensate internal structural changes. Third, to take advantage of the wealth of flight data, neural network learning is adopted and the predictive error signal is fed back to the control system. Finally, the simulation studies are given to illustrate the effectiveness of proposed control strategy

15:40-16:00	WeB1.6

Cooperative Transportation of a Cable-Suspended Load: Dynamics and Control, pp. 224-233

Costantini, Elia	University of Bologna
de Angelis, Emanuele Luigi	University of Bologna
Giulietti, Fabrizio	Università Di Bologna

The cooperative transportation of a cable-suspended load by two rotorcraft is analyzed. First, the equations describing a system made of three-point masses and two rigid cables are obtained. Then, the model is linearized about the hovering condition and analytical expressions are derived to describe the eigenstructure of the open-loop system. Based on the problem parametrization, the different dynamic modes are discussed with special focus on payload swing. A controller is proposed that allows the agents in the formation to simultaneously perform trajectory-tracking, formation geometry keeping, and payload swing stabilization. Although closed-loop stability is preliminary investigated in a linear framework, validation of the approach is performed in a realistic simulation scenario where two multirotors are modeled as rigid bodies under the effect of external disturbances and rotor-generated forces and moments, as obtained by Blade Element Theory. The proposed method has the merit of relative simplicity and is shown to significantly improve vehicle flying qualities of future delivery operations, while minimizing hazardous payload oscillations and reducing energy demand.

WeB2 **UAS Applications II** (Regular Session)	**MIKIS 2**
Chair: Gonzalez, Luis Felipe	Queensland University of Technology (QUT)/ QUT Centre for Robotics
Co-Chair: Tsourdos, Antonios	Cranfield University

14:00-14:20	WeB2.1

A Behavior Tree Approach for Battery-Aware Inspection of Large Structures Using Drones, pp. 234-240

Martinez Rocamora Junior, Bernardo	West Virginia University
Galvao Simplicio, Paulo Victor	West Virginia University
Pereira, Guilherme	West Virginia University

Electric multi-rotor drones have been used to inspect several structures, including large buildings and dams. In these inspections, energy consumption is a concern. To prevent the drone from running out of battery, commercial drones usually come back to their home position when the battery level reaches a minimum threshold. The pilots then need to replace the battery and use their own experience to restart the inspection mission approximately from where it ended before the drone returned home. Instead of relying on the human operator, in this paper, we automate this process using behavior trees, which is an effective way to perform autonomous mission control and supervision. By integrating battery management strategies into a behavior tree framework, this paper demonstrates the drone's adaptive and resilient decision-making when confronted with limited power constraints. We implemented our methodology using a commercial drone and tested the proposed ideas in a photogrammetry-based inspection task.

14:20-14:40	WeB2.2

A Data-Driven Method for Estimating Formation Flexibility in Beyond-Visual-Range Air Combat, pp. 241-247

Scukins, Edvards	SAAB Aeronautics
Negrao Costa, Andre	KTH
Ögren, Petter	KTH

Tactical decisions in air combat are typically evaluated using experience as a basis. Pilots undergo frequent training in various air combat processes to enhance their combat proficiency and evaluation skills. Having the Situational Awareness (SA) necessary to evaluate the effects of multiple missile threats can often be challenging. This study provides a new method for calculating an aircraft fleet's maneuver flexibility in a Beyond-Visual-Range (BVR) setting. Sustaining a high degree of flexibility is necessary to adapt to unforeseen circumstances in BVR air combat. To do that, we employ Deep Neural Networks (DNN) to capture the result of a high-performance aircraft model in the presence of adversarial BVR missiles. We then modify our approach to calculate the aircraft's maneuverability concerning an opposing fleet, looking at the advantages and disadvantages of several flight formations. Finally, we consider the anticipated threat from an incoming opponent formation and optimize the counter-formation. This methodology offers a more sophisticated comprehension of aircraft maneuver flexibility within a BVR framework and aids in developing flexible and efficient decision-making techniques for air combat.

14:40-15:00	WeB2.3

Real-Time and On-Board Anomalous Command Detection in UAV Operations Via Simultaneous UAV-Operator Monitoring, pp. 248-255

Elia, Rafaella	University of Cyprus
Theocharides, Theocharis	University of Cyprus

Constant technological advancements in the area of Remotely Operated Vehicles (ROVs) and specifically Unmanned Aerial Vehicles (UAVs), facilitate their widespread use in a variety of safety-critical applications. Sometimes, the operator is required to control the vehicle in harsh and stressful situations. Stress and fatigue can be challenging factors that can compromise the outcome and safety of the mission. Therefore, the operator is prone to potentially issue involuntary movements to the controller of the UAV. Nevertheless, real-time monitoring of the operator and the UAV can prevent possible accidents. In this work, we present a feature-based Machine Learning (ML) approach for the classification of abnormal commands, via simultaneous monitoring of the human operator and the UAV, during a mission. The proposed classification targets onboard implementation on the UAV and operates in real-time. We provide experimental results using Jetson Xavier NX as an experimental platform that includes trade-offs across all the performance metrics, where we achieve 82% accuracy with minimal processing time (9ms) and energy consumption (5mJ).

15:00-15:20	WeB2.4

Swarm Decoys Deployment for Missile Deceive Using Multi-Agent Reinforcement Learning, pp. 256-263

Bildik, Enver	Cranfield University
Perrusquía, Adolfo	Cranfield University
Tsourdos, Antonios	Cranfield University
Inalhan, Gokhan	Cranfield University

The development of novel radar seeker technologies has improved the hit-to-kill capability of missiles. This is particularly worrying in safety and security domains that need the design of appropriate countermeasures against adversarial missiles to ensure protection of naval facilities. This paper aims to contribute to these domains by developing an artificial intelligence (AI) based decoy deployment system capable of deceiving the missile threat. Here, a Multi-Agent Deep Deterministic Policy Gradient (MADDPG) algorithm is developed to maximise the distance between the target and the missile by learning the optimal/near optimal route planning of the six decoys to reach the global mission. As a case study, the deployment of six decoys from the top deck of the main platform is assumed. The decoys are launched from the platform at the initial phase of the mission, and they establish a leader follower formation that enhances the signal strength of the swarm decoys. The reward function is designed to guarantee a triangular formation configuration for swarm decoys. The reported results show that the proposed approach is capable to deceive the missile threat and has the potential to be integrated in current naval platforms.

15:20-15:40	WeB2.5

Machine Learning Based Damage Detection in Photovoltaic Arrays Using UAV-Acquired Infrared and Visual Imagery, pp. 264-271

Barrett, Aidan	Queensland University of Technology
Bratanov, Dmitry	Queensland University of Technology
Amarasingam, Narmilan	Queensland University of Technology
Sera, Dezso	Queensland University of Technology
Gonzalez, Luis Felipe	Queensland University of Technology (QUT)/ QUT Centre for Robotics

The rapid global expansion of solar panel installations necessitates more efficient and cost-effective methods for performance monitoring and maintenance. The New England Solar Project, Australia's largest solar installation is a prime example of the scale and complexity of modern solar farms, making it increasingly challenging to rely solely on manual ground-based inspections. This paper addresses the challenge by focusing on the integration of unmanned aerial systems (UAS) based imagery and deep learning (DL) techniques to develop a semi-automated pipeline for accurately identifying and classifying photovoltaic (PV) cell surface damage. The study leverages the YOLOv8 and Faster R-CNN models to achieve this goal. Drone based visual and infrared spectrum imagery collected from a solar installation site in Queensland, Australia, during October 2022 form the basis of the dataset, enabling the training and evaluation of these models. Three distinct damage classifications (Single-Cell, Multi-Cell, and Surface-Anomaly) were established with input from a subject matter expert to ensure accurate categorization of damage types. The research results indicate promising outcomes for classifying the distinct damage classes. The YOLOv8s-seg model achieved a mean average precision (mAP) of 87% to segment the solar panels. The YOLOv8m model, trained with a relatively small dataset, achieved a commendable mAP of 76% for solar panel damage detection. The Faster R-CNN model showed potential in detecting damage with high confidence, although a more comprehensive evaluation is needed. This research contributes to the broader goal of enhancing preventive maintenance practices, thereby reducing damage-related losses, and ensuring the long-term sustainability of solar installations.

15:40-16:00	WeB2.6

UAV-Assisted Maritime Search and Rescue: A Holistic Approach, pp. 272-279

Messmer, Martin	University of Tubingen
Kiefer, Benjamin	University of Tubingen
Varga, Leon Amadeus	University of Tubingen
Zell, Andreas	University of Tübingen

In this paper, we explore the application of Unmanned Aerial Vehicles (UAVs) in maritime search and rescue (mSAR) missions, focusing on small fixed-wing drones and quadcopters. We address the challenges and limitations inherent in operating some of the different classes of UAVs, particularly in search operations. Our research includes the development of a comprehensive software framework designed to enhance the efficiency and efficacy of SAR operations. This framework combines preliminary detection onboard UAVs with advanced object detection at ground stations, aiming to reduce visual strain and improve decision-making for operators. It will be made publicly available upon publication. We conduct experiments to evaluate various Region of Interest (RoI) proposal methods, especially by imposing simulated limited bandwidth on them, an important consideration when flying remote or offshore operations. This forces the algorithm to prioritize some predictions over others.

WeB3	**KAM**
Path Planning II (Regular Session)	
Chair: Chakravarthy, Animesh	University of Texas at Arlington
Co-Chair: Janabi Sharifi, Farrokh	Toronto Metropolitan University

14:00-14:20	WeB3.1

Turbulence-Aware UAV Path Planning in Urban Environments, pp. 280-285

Aldao Pensado, Enrique	University of Vigo
Fontenla Carrera, Gabriel	University of Vigo
Veiga-López, Fernando	University of Vigo
Gonzalez Jorge, Higinio	University of Vigo
Martin, Elena	University of Vigo

Wind turbulence is a critical factor for the safety of Urban Air Mobility operations. In urban environments, buildings and structures can generate irregular wind currents that may compromise the stability of aircraft. This poses a high risk due to the potential severity of an accident in these areas. For these reasons, this paper introduces a risk-aware path planning solution for Urban Air Mobility applications, including Computational Fluid Dynamics (CFD) simulations that predict atmospheric wind at urban environments. The generated algorithm provides safe and efficient routes, avoiding flight through regions with significant turbulence. A practical case study was conducted to demonstrate the strong capabilities of the proposed solution.

14:20-14:40	WeB3.2

Optimizing Routes of Heterogenous Unmanned Systems Using Supervised Learning in a Multi-Agent Framework: A Computational Study, pp. 286-294

Ramasamy, Subramanian	University of Illinois at Chicago
Mondal, Mohammad Safwan	University of Illinois at Chicago
D. Humann, James	Army Research Laboratory

Dotterweich, James	Army Research Lab
Reddinger, Jean-Paul	Army Research Lab
Childers, Marshal	Army Research Lab
Bhounsule, Pranav	University of Illinois at Chicago

Fast-paced but power-hungry Unmanned Aerial Vehicles (UAV) may collaborate with slow-paced Unmanned Ground Vehicles (UGV) acting as mobile recharging depots to perform large-scale and long-duration tasks such as in disaster relief management. It is important to be able to create high-quality vehicle routes in a short span of time to enable in-field, real-time deployment. A two-level optimization enables a tractable approach to solving such NP-hard combinatorial optimization problems, and it consists of an outer-level UGV route optimization to compute recharge locations and an inner-level UAV optimization to compute a sequence of nodes and recharging nodes to be visited. We consider various approaches to solve this two-level optimization. Method 1: Genetic algorithm for global search of UGV routes and a constraint programming solver for the UAV routes. Method 2: A-Teams framework that uses a combination of Genetic Algorithm (GA) for global search and Nelder-Mead for local search for UGV routes and constraint programming for inner routes, Method 3: Our proposed A-Teams by adding a supervised learning prediction step to veto out suboptimal evolutions from GA to the UGV route and constraint programming for the inner level, Method 4: Our proposed A-Teams for outer level but with a mixed integer programming solver for the inner-level. Our results on test cases show that the proposed Method 3 produces an optimal solution 30% faster than Method 2, 79% faster than Method 1, and 83% faster than Method 4 while being within 2% of the solution optimality across these methods.

14:40-15:00	WeB3.3

Lander.AI: DRL-Based Autonomous Drone Landing on Moving 3D Surface in the Presence of Aerodynamic Disturbances, pp. 295-300

Peter Vimalathas, Robinroy	Skolkovo Institute of Science and Technology
Ratnabala, Lavanya	Skolkovo Institute of Science and Technology
Tareke, Demetros Aschalew	Skolkovo Institute of Science and Technology
Fedoseev, Aleksey	Skolkovo Institute of Science and Technology
Tsetserukou, Dzmitry	Skolkovo Institute of Science and Technology

Autonomous drone landing on dynamic platforms presents formidable challenges due to unpredictable velocities and aerodynamic disturbances. This study introduces an advanced Deep Reinforcement Learning (DRL) agent, Lander.AI, designed to navigate and land on 3D moving platforms in the presence of aerodynamic disturbance and sudden velocity changes, thereby enhancing drone autonomy and safety. Lander.AI is trained in the gym-pybullet-drone simulation, an environment that mirrors real-world complexities, including wind disturbance, to ensure the agent's robustness and adaptability. The agent's capabilities were empirically validated with Crazyflie 2.1 drones across various test scenarios, encompassing both simulated environments and real-world conditions. The experimental results showcased Lander.AI's high-precision landing and its ability to adapt to moving platforms, even under wind-induced disturbances. Furthermore, the system performance was benchmarked against a baseline Proportional-–integral–derivative (PID) controller augmented with an Extended Kalman Filter, illustrating significant improvements in landing precision and error recovery. This research not only advances drone landing technologies, essential for inspection and emergency applications but also highlights the potential of DRL in addressing intricate aerodynamic challenges.

15:00-15:20	WeB3.4

3D Collision Cone-Based Reactive Avoidance of Multiple Dynamic Obstacles Applied on a Quadrotor Platform, pp. 301-308

Kashyap, Abhishek	University of Texas at Arlington
Rijal, Rishab	University of Texas at Arlington
Gyawali, Ravi	University of Texas at Arlington
Chakravarthy, Animesh	University of Texas at Arlington

The ability for UAVs to achieve reactive collision avoidance in environments comprising multiple moving objects is an important enabler for UAVs to perform autonomous missions. The relative shapes of the objects play an important role in the determination of appropriate maneuvers for collision avoidance. Literature largely models the shapes of objects as spheres. However, this can make the avoidance maneuvers very conservative, and this is particularly true when the objects are of elongated shape and/or are non-convex. In this paper, we model the shapes of the objects using suitable combinations of ellipsoids and one-sheeted or two-sheeted hyperboloids and use a collision cone-based approach to compute collision avoidance maneuvers. The algorithm to construct 3D collision cones for such object shapes is described, followed by computation of an avoidance acceleration law. The algorithm is validated on a PX4 based UAV in ROS-Gazebo, and this is followed by experiments on an actual quadrotor system wherein all the computations for the 3D collision cone and avoidance acceleration laws are performed on an onboard computer in real-time.

15:20-15:40	WeB3.5

Online State-To-State Time-Optimal Trajectory Planning for Quadrotors in Unknown Cluttered Environments, pp. 309-316

Nguyen, Thai Binh	Federation University Australia
Murshed, Manzur	Deakin University
Choudhury, Tanveer Ahmed	Federation University Australia
Keogh, Kathleen	Federation University
Kahandawa, Gayan	Federation University
Nguyen, Linh	Federation University Australia

This paper introduces the first planner, called STAMINER (STAte-to-state time-optimal memoryless planNER), which is able to real-time plan collision-free, local time-optimal trajectories in unknown and cluttered settings without the need for any maps or fused occupancy

structures of the surrounding environment. Specifically, our method explores a library of state-to-state time-optimal trajectories in a memoryless collision-checking framework. It iteratively searches for the best trajectory with the longest projection on the direction to the goal. Results obtained from two different simulated cluttered scenarios demonstrate that our planner outperforms the state-of-the-art baselines concerning global finishing time. Furthermore, real-world flight trials were conducted to validate the effectiveness of our algorithm in an actual quadrotor. Finally, this paper also provides a mathematical proof of the solution characterization that is not available in the literature for the considered state-to-state time-optimal trajectory generation problem.

15:40-16:00	WeB3.6

Benchmarking Off-Policy Deep Reinforcement Learning Algorithms for UAV Path Planning, pp. 317-323

Garg, Shaswat	University of Waterloo
Masnavi, Houman	Toronto Metropolitan University
Fidan, Baris	University of Waterloo
Janabi Sharifi, Farrokh	Toronto Metropolitan University
Mantegh, Iraj	National Research Council Canada

This paper presents a benchmarking framework for reinforcement learning (RL) algorithms in unmanned aerial vehicle (UAV) path planning. The focus is on assessing the generalization from simulation to real-world deployment. The benchmark includes optimal simulation environments, a comparative analysis of off-policy RL algorithms (DDPG, TD3, SAC, SoftQ), and a simulation-to-reality transfer procedure. Contributions encompass environment design, algorithm comparison, and a transfer method. Results show DDPG excelling in maximum reward, while TD3 demonstrates superior collision avoidance. Generalization is tested in diverse environments, revealing algorithmic strengths and weaknesses. The study concludes with insights and outlines for future research, including refining metrics, exploring more algorithms, and incorporating vision-based RL for UAV path planning.

WeB4	**DILOVO**
Regulations (Regular Session)	
Chair: Krause, Stefan	German Aerospace Center
Co-Chair: Grigoriou, Yiannis	KIOS Research and Innovation Center of Excellence, University of Cyprus

14:00-14:20	WeB4.1

Enhancing Public Acceptance of the Advanced Air Mobility (AAM) Ecosystem Technology: Exploring Conceptual Theoretical Frameworks and Regulatory Support, pp. 324-330

Chaisit, Ittiporn	Loughborough University
Hubbard, Ella-Mae	Loughborough University
Lepper, Paul	Loughborough University

The advent of Advanced Air Mobility (AAM) can potentially improve urban transportation by proposing a transformational vision of aerial mobility to transport people and parcels, with the advanced capacity of Unmanned Aircraft System (UAS) which now has expanded the concept to include not only with Drones but also other type of aerial vehicles such as eVTOL aircraft. This could foster the development of smart city vision in many countries. However, to implement this emergent technology in wider society, public acceptance needs to be addressed. Even though there is a regulation related to drone operation, making people aware is also paramount to ensure that they will perceive the operation of drones as being able to support a better society and will lead to more effective deployment of this technology ecosystem. This paper aims to investigate the relevant conceptual framework to support the facilitation of the Advanced Air Mobility (AAM) Ecosystem, the readiness for drone operation in wider society and, especially, explore how to gain more public acceptance in terms of building trust in communities, focusing on the role of existing regulatory frameworks in shaping a harmonious and accepted future. This study will provide an overview of the AAM ecosystem depiction and the initial strategy to help gain more acceptance from the public, especially with its infrastructure and facilitation to support this technology through building awareness of relevant regulatory safeguards.

14:20-14:40	WeB4.2

AI Empowered Drones: Analyzing Challenges and Crafting Solutions for Effective Regulation in Autonomous Operations from the Brazilian Landscape Perspective, pp. 331-338

Formenton Vargas, Isadora	Rossi, Maffini, Milman & Grando Advogados
Pignaton de Freitas, Edison	Federal University of Rio Grande Do Sul

This paper explores the regulatory landscape of autonomous operations of Artificial Intelligence (AI) empowered drones, with a specific focus on the Brazilian context. This study identifies and analyzes the challenges inherent in regulating such operations, considering factors such as safety, privacy, and technological advancements. Through a comprehensive examination, the study proposes solutions aimed at enhancing regulatory effectiveness while fostering innovation and competitiveness in the drone industry. By addressing these challenges from a Brazilian standpoint, the work contributes to the broader discussion on the regulation of autonomous drone operations in the global arena.

14:40-15:00	WeB4.3

Field Report: Integration of a Parachute Rescue System into an Existing Unmanned Aerial Vehicle, pp. 339-346

Krause, Stefan	German Aerospace Center
Cain, Sebastian	German Aerospace Center
Peters, David	German Aerospace Center

In many parts of the world, such as Europe, the operation of drones requires the approval of a competent authority if the intended

operation could pose a risk to third parties. The possible risks are determined, for example, by the size of the drone, whether the operation is planned in the vicinity of people or beyond the line of sight of a pilot. The permit may, among others, be achieved with the SORA process, that is proposed by JARUS and accepted by EASA as acceptable means of compliance. During this process, the risks of operation are determined and the requirements that the operator must fulfill to fly the drone are assessed. The risks in the air and on the ground as well as possible remedial measures specific to this operation are examined and compared. A possible mitigation to reduce the estimated ground risk is a reduction of the effects in case the drone impacts the ground. One way to implement this mitigation is to integrate a parachute in the drone and show that the parachute is applicable to cover all failure cases of the drone and reduces the impact energy in a case of crash. This paper presents a way how we developed, tested, and integrated a parachute rescue system in an already existing research drone prototype which only exists once. Therefore, tests to evaluate the parachute and its functionality which are likely to destroy the drone were not possible. An applicable parachute system was not available, so one was developed and evaluated in representative airflow exposition on a driving testbed and laboratory tests. Finally, we will give some advice that we have learned during this work and that may also help other working groups if they are also planning a drone mission with a parachute rescue system.

15:00-15:20	WeB4.4

The Legality of Countering Potential Threats Posed by Drones under International Air Law, pp. 347-354

Kurtpinar, Elif Öykü	Leiden University
Scott, Benjamyn	Leiden University

The Convention of International Civil Aviation of 1944 recognizes that States must refrain from using weapons against civil aircraft while they are in flight. However, the rise in non-cooperative unmanned aircraft raises the question of how these can be lawfully intercepted.

15:20-15:40	WeB4.5

Enhancing the Safety of Multi-UAS Urban Operations with SORA, pp. 355-362

Grigoriou, Yiannis	KIOS Research and Innovation Center of Excellence, University Of
Savva, Antonis	University of Cyprus
Kolios, Panayiotis	University of Cyprus
Chatzipanagiotis, Michael	University of Cyprus
Timotheou, Stelios	University of Cyprus

Unmanned Aircraft Systems (UAS) play a pivotal role in a variety of modern applications, with traffic monitoring emerging as a critical use case. This study presents the Specific Operations Risk Assessment (SORA) 2.0 framework as applied to UAS operations dedicated for traffic monitoring in urban environments. A comprehensive risk assessment is provided by incorporating real-world scenarios and addressing practical aspects of traffic monitoring missions. A fleet of semi-autonomous drones is employed to safely acquire video footage of traffic for further analysis, based on a detailed elaboration of SORA methodology steps. In this regard, enhancements are proposed for structuring the Air Risk Class assessment and corresponding mitigation measures, as well as recommendations concerning Multi-UAS and autonomous operations, aiming to improve the methodology. As the demand for UAS operations in urban environments, including efficient and secure traffic management solutions, constantly increases, this study aspires to contribute to the UAS operational safety and regulatory framework.

15:40-16:00	WeB4.6

High-Altitude Platform Stations (HAPS); Regulatory Obstacles Blocking Their Deployment, pp. 363-369

Stellatou, Sofia	Access Partnership
Erotokritou, Chrystel	Access Partnership

This article delves into the evolution of High-Altitude Platform Stations (HAPS) as a vital technology for addressing the digital divide. From their inception in WRC-97 to recent WRC-23 developments, the focus is on unmanned HAPS, their technical specifications, deployment methods, and regulatory advancements in low- and medium-risk operations. Ongoing projects exemplify applications from 5G connectivity to disaster relief. The advantages of HAPS over satellites, including cost-effectiveness and reusability, are explored. Regulatory challenges worldwide hinder market access, and potential solutions are proposed, emphasizing the need for coordinated efforts to establish clear and harmonized frameworks. The authors will argue that the integration of HAPS represents a major opportunity to radically innovate in airspace management at the national, regional, and international levels. The article will analyse whether current aviation laws, radio spectrum regulation and industry standards are appropriate tools to enable HAPS to be promptly commercially deployed. Addressing these challenges is crucial for leveraging HAPS to close the digital divide and achieve universal internet access.

WeC1	**MIKIS 1**
Multirotor Design and Control III (Regular Session)	
Chair: Zolotas, Argyrios	Cranfield University
Co-Chair: Lee, Jayden Dongwoo	Korea Advanced Institute of Science and Technology

16:30-16:50	WeC1.1

Koopman-Based Reduced Order Controller Design for Quadrotors, pp. 370-375

Martini, Simone	University of Denver
Valavanis, Kimon P.	University of Denver
Stefanovic, Margareta	University of Denver
Rizzo, Alessandro	Politecnico Di Torino
Rutherford, Matthew	University of Denver

A novel Koopman-based reduced order controller for quadrotor stabilization and trajectory tracking is derived, implemented, and tested.

Controller design exploits Koopman spectral theory for which an infinite dimensional Koopman-based linear dynamics model, embedding the dynamics of the underlying nonlinear system, may be represented by a finite subset of the eigenfunctions of the Koopman operator. The proposed controller exploits the fact that, for Hamiltonian systems, the Hamiltonian function is always an eigenfunction of the Koopman operator. Using this approach, a hierarchical controller is derived that is composed of a PID outer loop position controller and a state dependent Riccati equation Koopman-Hamiltonian inner loop attitude controller. A key advantage of this approach is that it achieves multivariable attitude control using a single scalar Hamiltonian function, thus, drastically simplifying controller design. Moreover, by minimizing an energy function, the optimal controller guarantees optimal trajectory tracking. Results show that the designed controller can stabilize the quadrotor dynamics and to track a helix trajectory even in the presence of wind gust disturbances, drag effects, and first order motor dynamics.

16:50-17:10	WeC1.2

Are Tilt Quadrotors More Energy-Efficient Than Conventional Quadrotors? a Preliminary Study, pp. 376-381

Eliker, Karam	Technical University of Denmark
Jouffroy, Jerome	University of Southern Denmark

This paper studies the energy-saving potential of tilt-rotor drones under the presence of wind disturbances. Owing to the symmetry of the problem, a mathematical model including simple computational fluid dynamics (CFD) analysis-based aerodynamics is first presented. To deal with the minimum energy problem, a minimum energy super-twisting algorithm (STA) is used for stabilization around any desired pitch angle, while the extremum-seeking approach is employed to calculate the optimal pitch angle to minimize the consumed energy in real-time. Numerical simulation and comparison studies with both a conventional quadrotor and a tilt-quadrotor stabilized at zero pitch angle show that the proposed method exhibits an interesting potential in terms of energy consumption, thus resulting in the possibility for greater flight durations.

17:10-17:30	WeC1.3

Data-Driven Fault Detection and Isolation for Quadrotor Using Sparse Identification of Nonlinear Dynamics and Thau Observer, pp. 382-389

Lee, Jayden Dongwoo	Korea Advanced Institute of Science and Technology
Im, Sukjae	Korea Advanced Institute of Science and Technology
Bang, Hyochoong	Korea Advanced Institute of Science and Technology

This paper suggests data-driven fault detection and isolation for a quadrotor system using sparse identification of nonlinear dynamics (SINDy) and Thau observer. We propose a novel fault detection method to solve the challenge of a quadrotor with unknown dynamic effect and parameter uncertainty. The SINDy can discover the governing equations of target systems with low data assuming that few functions have the dominant characteristic of the system. Using these properties, system model identification is performed to obtain a nonlinear term that is needed to apply a Thau observer for a quadrotor system. First, the SINDy model is derived by considering a gyroscopic effect and an aerodynamic effect. Second, a SINDy-based Thau observer is proposed to generate a residual that can be used to determine a faulty actuator. Finally, results of the simulation demonstrate that the suggested observer outperforms the Thau observer in detecting faults, even in the presence of uncertain parameters and unknown model effects.

17:30-17:50	WeC1.4

Automatic Recovery of Fixed-Wing Unmanned Aerial Vehicle Using Bluetooth Angle-Of-Arrival Navigation, pp. 390-397

Sollie, Martin Lysvand	Norwegian University of Science and Technology
Gryte, Kristoffer	Norwegian University of Science and Technology
Bryne, Torleiv Håland	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

We demonstrate that the Bluetooth 5.1 Angle-of-Arrival feature can be used as a navigation system for automatic recovery of a fixed-wing unmanned aerial vehicle (UAV), guiding the UAV into an arrest system such as a suspended net, independently from global navigation satellite systems (GNSS). The effect of multipath signal interference on the elevation angle estimate is handled by a constant offset calibration. In field experiments, we demonstrate approach path following using a Skywalker X8 fixed-wing UAV and a Bluetooth antenna array. For 39 approach repetitions the resulting impact positions 40m in front of the array had standard deviations of 0.41m horizontally and 0.32m vertically according to precise RTK GNSS positioning used for comparison.

17:50-18:10	WeC1.5

A Modular UAV Hardware Platform for Aerial Indoor Navigation Research and Development, pp. 398-404

Deliparaschos, Kyriakos	Cyprus University of Technology
Loizou, Savvas	Cyprus University of Technology
Zolotas, Argyrios	Cranfield University

This study introduces a specialised hardware platform designed for indoor navigation, featuring a quadrotor equipped with either a NVIDIA Jetson Nano or a Z-turn Zynq onboard computer. The onboard computer communicates via ROS2 with the flight controller, the Inertial Measurement Unit (IMU), Ultra-WideBand (UWB) localisation system, stereo camera, Light Detection and Ranging (LiDAR), and ultrasonic sensors. The focus is on creating a low-cost modular Unmanned Aerial Vehicle (UAV) system adaptable to various indoor navigation applications. The modular design encompasses different onboard computer platforms and sensor configurations, allowing for easy adaptation to research experiment setups. The objective is to facilitate the transition from simulated and simplified laboratory experiments to deploying aerial robots in challenging real-world conditions. The paper explores the hardware architecture and Robot Operating System 2 (ROS2)-based communication system of the UAV and provides a weight analysis and power estimation.

18:10-18:30	WeC1.6

Modelling of Ground and Ceiling Effects for Quadcopters Based on Experimental Data, pp. 405-412

David Du Mutel de Pierrepont Franzetti, Iris	Politecnico Di Torino

Parin, Riccardo	Eurac Research
Carminati, Davide	Politecnico Di Torino
Capello, Elisa	Politecnico Di Torino

This work is focused on the identification of a model based on experimental results for ground and ceiling effects for small scale quadrotors. Experiments are conducted using a fixed test bed and a force-torque sensor that measures the total thrust of a quadcopter when placed at different distances from horizontal surfaces. Two propeller sizes are considered at constant pressure and temperature conditions. Two different modelling approaches are proposed: an exponential parametric curve fitting method and a Gaussian Process regression method. Results are compared to ground effect models present in literature. We present a novel ground and ceiling parametric model in which the out-of-ground/out-of-ceiling thrust is explicitly modelled. Moreover, an approach based on Gaussian process regression is explored, showing its potential for UAV applications.

WeC2	**MIKIS 2**
UAS Applications III (Regular Session)	
Chair: Vitzilaios, Nikolaos	University of South Carolina
Co-Chair: Brandao, Alexandre Santos	Federal University of Vicosa

16:30-16:50	WeC2.1

Enhancing Traffic State Estimation Using UAV-Based Measurements, pp. 413-420

Englezou, Yiolanda	KIOS Research and Innovation Center of Excellence, University Of
Timotheou, Stelios	University of Cyprus
Panayiotou, Christos	University of Cyprus

Traffic state estimation is a challenging task due to the collection of sparse and noisy measurements from specific points of the traffic network. The emergence of Unmanned Aerial Vehicles (UAVs) provides new capabilities for traffic state estimation using density measurements at irregular time-points from all links of a given network under study. This work proposes a data-driven traffic density estimation method utilising measurements collected from a swarm of UAVs deployed over the network under study and no traffic models or historical data are required. A simulation study is conducted to compare the quality of information obtained from UAV-based measurements to the information provided by other sensing technologies, particularly fixed-location sensors and Connected and Automated Vehicles (CAVs). Notably, while CAV-based and UAV-based sensing provide information with higher spatiotemporal resolutions compared to fixed-location sensors, UAV-based sensing exhibits higher estimation accuracy even under low penetration rates of UAVs flying above the network and low percentages of network coverage.

16:50-17:10	WeC2.2

Drones-As-A-Service for Efficient Critical National Infrastructure Operations: Reducing the Time from Image Capture to Insight Generation, pp. 421-429

Duke, Alistair Keith	BT
Shimmon, Ryan	BT
Wiseman, Richard	BT
Zheng, Hao	RoboK
Yue, Dingcheng	RoboK
Seghers, Aamna	RoboK
Anastassacos, Edward	HEROTECH8
McMaster, Ciaran	Herotech8
Mendez, Arthur	Herotech8
Moorcroft, Phillip	Connected Places Catapult
Laouici, Sophia	Connected Places Catapult
Tideswell, Tom	Kier Transportation
Lyons, Connor	Associated British Ports

This paper describes the work of the InDePTH project which is focused on the use of autonomous drones to deliver efficient critical infrastructure operations for ports and highways, increasing safety and efficiency and minimizing the economic impact of interventions. InDePTH is utilizing autonomous drones to deliver regular surveying of infrastructure estates, to obtain detailed insight into these dynamic environments. The project is integrating next-generation sensing, data and image processing facilities and autonomous drones, currently commercialized as drone-in-a-box (DIAB). The paper describes the challenges facing ports and highways operators, the novel aspects of the InDePTH approach that can be applied to these challenges and the results from our deployments and trials in live environments.

17:10-17:30	WeC2.3

Evaluation and Comparison of State and Disturbance Observers for a Terrestrial Hexacopter, pp. 430-435

Sopegno, Laura	University of Palermo
Pedone, Salvatore	University of Palermo
Rutherford, Matthew	University of Denver
Livreri, Patrizia	University of Palermo
Valavanis, Kimon P.	University of Denver

Unmanned Aerial Vehicles (UAVs) have been used for a wide range of civil and public domain applications, as well as for missions to

Mars, during the last two decades. Multirotor UAV configurations, such as hexacopters, strike a balance between different design considerations, offering improved performance and reliability compared to other options. For autonomous exploration scenarios, Guidance, Navigation, and Control (GNC) subsystems play a critical role in ensuring hexacopter stability and autonomy, especially in GPS-denied environments. However, external disturbances and system uncertainties, such as sensor noise, present challenges, impacting both navigation accuracy and control integrity. To address this, two state observers, the Unknown Input Observer (UIO) and the Extended State Observer (ESO) are presented and analyzed. Performance evaluation and comparison of both observers, UIO and ESO, is conducted with a focus on estimating the states of a terrestrial flight hexacopter in the context of an autonomous navigation mission. The underlying hexacopter mathematical model includes external disturbances, such as aerodynamic drag, and system uncertainties. The simulations are performed in a Matlab/Simulink environment. Both observers offer robust solutions for estimating system states and compensating for disturbances, and the superiority of the UIO when dealing with random sensor bias is demonstrated.

17:30-17:50	WeC2.4

UAV-Based Optimization for Fruit Counting in Greenhouses, pp. 436-441

R. Vasconcelos, João Vítor	Universidade Federal De Viçosa
Miranda Hudson, Thayron	Universidade Federal De Viçosa
dos Santos, Andre Gustavo	Universidade Federal De Viçosa
Saska, Martin	Czech Technical University in Prague FEE
Brandao, Alexandre Santos	Universidade Federal De Viçosa

This paper presents a solution for counting fruit in agricultural greenhouses using Unmanned Aerial Vehicles (UAVs). Initially, a heuristic based on Simulated Annealing was used to optimize the UAV's trajectory, ensuring efficient coverage of the beds. Next, digital image processing (DIP) techniques were implemented to count the fruit, including depth segmentation, application of bounding boxes, color filtering, and element counting. The DIP accuracy was evaluated in multiple scenarios and the results indicate high reliability in fruit counting, with the potential to optimize agricultural operations and provide valuable information to producers. Possible future improvements could include further refinements in image processing to increase the accuracy of counting other fruits. Ultimately, this work contributes to the advancement of automation in agriculture by offering a viable and efficient solution for counting fruit in greenhouses using UAVs.

17:50-18:10	WeC2.5

DroneRanger: Vision-Driven Deep Learning for Drone Distance Estimation, pp. 442-449

Azad, Hamid	University of Ottawa
Mehta, Varun	University of Ottawa
Mantegh, Iraj	National Research Council Canada
Bolic, Miodrag	University of Ottawa

This paper introduces a novel approach to estimating the distance between a drone and a camera using deep learning techniques. The proposed method employs a low-complexity convolutional neural network (CNN), called DroneRanger, to analyze the captured 2D image and estimate the 3D drone distance. Three types of input data for the CNN regression model are investigated, including extended bounding box, resized bounding box, and resized bounding box with additional size information. The effectiveness of the method is demonstrated through experiments conducted on both synthetic datasets using AirSim and real flight tests, showcasing its performance across various simulation conditions, including different weather and environments. Furthermore, experiments conducted on real-world data captured using camera-equipped drones validate the method's performance (with RMSE of distance estimation error less than 5 meters) under practical conditions. To address uncertainties in training labels caused by localization information from GPS sensors, robust regression based on the Huber loss function is employed to improve accuracy. These findings suggest promising prospects for accurately estimating 3D distances from 2D images, highlighting the potential of the proposed approach for real-world problems in drone applications such as collision avoidance between drones.

18:10-18:30	WeC2.6

Applications of Digital Twins in UAVs, pp. 450-457

Sarantinoudis, Nikolaos	Technical University of Crete
Vitzilaios, Nikolaos	University of South Carolina
Arampatzis, George	Technical University of Crete

In recent years, Digital Twins (DTs) have been extensively used in numerous domains. On vehicular applications specifically, most are focused on ground vehicles with proven advantages. But how about the application of DTs in the UAV domain? This paper presents an extensive survey where we aim to address four related research questions, namely if DTs are used in UAVs, which are the applications of DTs in UAVs, if DTs can be applied to any UAV type and, finally, what are the specific tools used for DT implementation in the UAV domain. Using a well-defined research methodology, we collected and reviewed more than 70 publications on the subject. Through different categorizations of the publications under study and an aggregated presentation in tabular format, the reader can gain a thorough understanding of recent developments in this area of research.

WeC3	**KAM**
Path Planning III (Regular Session)	
Chair: Tsourveloudis, Nikos	Technical University of Crete
Co-Chair: Morrison, James R.	Central Michigan University

16:30-16:50	WeC3.1

Energy-Efficient Path-Planning for UAV Swarm Based Missions: A Genetic Algorithm Approach, pp. 458-463

Kladis, Georgios P.	Hellenic Air Force Academy

Doitsidis, Lefteris — Technical University of Crete
Tsourveloudis, Nikos — Technical University of Crete

In all applications involving swarms, it's crucial for the group to achieve its objectives safely and with efficient energy utilisation, while adhering to constraints and meeting mission requirements. This article focuses on addressing the offline path planning problem for Unmanned Aerial Vehicles (UAVs), with a specific emphasis on enhancing energy efficiency. Each UAV in the swarm is guided along a candidate path represented by a Bezier curve, which evolves through a two-step procedure. Firstly, a genetic algorithm normalises the fitness function to ensure fair comparison of traits. Secondly, a multi objective swarm-based path planning approach is employed to find the most energy-efficient and safe route for the swarm, meeting predefined criteria. The designed solution paths accommodate the functional and physical limitations of aerial vehicles, while also considering factors such as vessel traffic and weather conditions in the operational area. Simulation examples demonstrate the effectiveness of this approach.

16:50-17:10	WeC3.2

Mission Planning for Photogrammetry-Based Autonomous 3D Mapping of Dams Using a Commercial UAV, pp. 464-471

Galvao Simplicio, Paulo Victor — West Virginia University
Pereira, Guilherme — West Virginia University

The application of autonomous unmanned aerial vehicles (UAVs) for conducting inspections of dams represents an innovative approach aimed at enhancing safety, efficiency, and cost-effectiveness. In this context, this paper presents algorithms for UAV mission design in autonomous dam inspections that include the creation of a 3D map based on photogrammetry. The algorithms were systematically developed to incorporate a comprehensive set of parameters that account for the geometric characteristics of the dam and adhere to photogrammetry specifications. To validate the proposed methodology, we utilized a commercial programmable quadrotor, specifically the Parrot Anafi USA Gov drone, which is equipped with high-quality cameras and can be programmed with the help of a software development kit (SDK) provided by the manufacturer. Our results demonstrate the efficacy of our method, highlighting how the generated maps can be used for hazard detection in the downstream slope of dams.

17:10-17:30	WeC3.3

Evaluating UAV Path Planning Algorithms for Realistic Maritime Search and Rescue Missions, pp. 472-479

Messmer, Martin — University of Tübingen
Zell, Andreas — University of Tübingen

Unmanned Aerial Vehicles (UAVs) are emerging as very important tools in search and rescue (SAR) missions at sea, enabling swift and efficient deployment for locating individuals or vessels in distress. The successful execution of these critical missions heavily relies on effective path planning algorithms that navigate UAVs through complex maritime environments while considering dynamic factors such as water currents and wind flow. Furthermore, they need to account for the uncertainty in searching for target locations. However, existing path planning methods often fail to address the inherent uncertainty associated with the precise location of search targets and the uncertainty of oceanic forces. In this paper, we develop a framework to develop and investigate trajectory planning algorithms for maritime SAR scenarios employing UAVs. We adopt it to compare multiple planning strategies, some of them used in practical applications by the United States Coast Guard. Furthermore, we propose a novel planner that aims at bridging the gap between computation heavy, precise algorithms and lightweight strategies applicable to real-world scenarios.

17:30-17:50	WeC3.4

Predictive Motion Planning for VTOL Landings on Vertically Moving Marine Platforms, pp. 480-487

Kholosi, Hazem — Middle East Technical University, ESEN System Integration LLC
Yayla, Metehan — Middle East Technical University
Kutlu, Aykut — Esen System Integration LLC
Soken, Halil Ersin — Middle East Technical University

This paper presents an algorithm developed for scheduling the landing of an aircraft on a vertically moving marine platform. The algorithm incorporates the relative velocity of the aircraft and marine platform, ensuring a higher probability of landing below the desired relative touchdown velocity. The detection of potential landing instant is dependent on a prediction algorithm that considers the platform's motion. Furthermore, the algorithm prioritizes landing at heave peak points on the platform, resulting in a more stable landing. The efficacy of the algorithm is demonstrated through numerical examples and software-in-the-loop (SITL) simulations on X-Plane flight simulator, showing safer landing compared to traditional scheduling methods. This algorithm has potential applications in the fields of commercial aviation and military operations where precision landing on moving platforms is crucial such as landing on ships and offshore oil rigs.

17:50-18:10	WeC3.5

Resource Schedules for Persistent UAV Systems with Logistics Replenishment Platforms: Petri Net Models and LP Formulation, pp. 488-495

Altaweel, Ammar — Central Michigan University
Neebraz, Mirza Essa — Central Michigan University
Morrison, James R. — Central Michigan University

Many unmanned aerial vehicles (UAVs) suffer from limited flight duration and thus long-term operations are prohibited. With replenishment of essential consumables, such as fuel and packages, by automated logistics service stations (LSS), persistent operations are enabled. However, persistent UAV operations require more than just LSS. Overall system resource requirements enabling the desired coverage as well as detailed schedules for the orchestration of the UAVs and LSS resources are essential. In this paper, we focus on a system of UAVs that are served by battery charging platforms seeking to provide a persistent UAV presence. We refine prior work that calculates the required resources for persistence. To generate detailed resource schedules, we first impose a sequential resource selection rule. This enables an extended Petri net model of the system behavior in the periodic regime that explicitly models resource pairing. A linear program (LP) to determine the firing times of events in the Petri net is developed. From this LP, detailed resource schedules are obtained. Further insights that can be deduced from the models are considered.

18:10-18:30	WeC3.6

Automated Real-Time Inspection in Indoor and Outdoor 3D Environments with Cooperative Aerial Robots, pp. 496-504

Anastasiou, Andreas	KIOS CoE, University of Cyprus
Zacharia, Angelos	KIOS CoE University of Cyprus
Papaioannou, Savvas	KIOS CoE, University of Cyprus
Kolios, Panayiotis	University of Cyprus
Panayiotou, Christos	University of Cyprus
Polycarpou, Marios M.	University of Cyprus

This work introduces a cooperative inspection system designed to efficiently control and coordinate a team of distributed heterogeneous UAV agents for the inspection of 3D structures in cluttered, unknown spaces. Our proposed approach employs a two-stage innovative methodology. Initially, it leverages the complementary sensing capabilities of the robots to cooperatively map the unknown environment. It then generates optimized, collision-free inspection paths, thereby ensuring comprehensive coverage of the structure's surface area. The effectiveness of our system is demonstrated through qualitative and quantitative results from extensive Gazebo-based simulations that closely replicate real-world inspection scenarios, highlighting its ability to thoroughly inspect real-world-like 3D structures.

WeC4	**DILOVO**
Airspace Management/Control (Regular Session)	
Chair: Mejias Alvarez, Luis	Queensland University of Technology
Co-Chair: Kim, Juyoung	Seoul National University

16:30-16:50	WeC4.1

Model-Free Control Design Using Incremental Approximate Dynamic Programming and Generalized Extended State Observer, pp. 505-511

Kim, Juyoung	Seoul National University
Lee, Hanna	Seoul National University
Lee, Youngjun	Seoul National University
Park, Jongho	Ajou University
Kim, Youdan	Seoul National University

A model-free control strategy is proposed which minimizes the cost function consisting of decision and observation. Real-time control can be achieved for unknown systems without relying on any pre-trained policies and model information. By estimating various external disturbances and model uncertainties to stably achieve the control goal, robustness can be improved. The numerical simulations demonstrate the effectiveness of the proposed method in controlling the acceleration of missiles.

16:50-17:10	WeC4.2

Fixed-Time Fractional-Order Sliding Mode Control for Image-Based Visual Servoing of Hexarotor, pp. 512-521

Kamath, Archit Krishna	Nanyang Technological University Singapore
Teng, Chan Nga	Tsinghua University
Feroskhan, Mir	Nanyang Technological University

This paper introduces a fixed-time fractional order sliding mode control (FTFOSMC) strategy designed for visual servoing applications using a hexarotor. In contrast to traditional finite-time sliding mode control approaches, the proposed method ensures the convergence of error trajectories to zero within a precisely defined time frame, irrespective of the system's initial conditions. The incorporation of fractional calculus in the control design minimizes chattering in the control effort, enhancing the strategy's suitability for real-time applications. The efficacy of the FTFOSMC strategy is demonstrated by integrating it with an image-based visual servoing approach on a hexarotor. Despite the nonlinear dynamics of the hexarotor and uncertainties introduced by the image node, the proposed controller effectively mitigates inherent chattering, achieving error convergence to zero within a fixed time based on fixed-time Lyapunov's stability theory. The paper further substantiates the superior performance of the proposed controller through a static platform landing task using AruCo markers, including a comparison with the existing finite-time sliding mode control strategy. The results affirm the effectiveness of the FTFOSMC approach and its potential to enhance the performance of hexarotor-based visual servoing applications in real-world scenarios.

17:10-17:30	WeC4.3

Updating Air Traffic Models Using Discrete Fréchet Distance, pp. 522-528

Chiaratti, Anthony	Queensland University of Technology
Mcfadyen, Aaron	Queensland University of Technology
Mejias Alvarez, Luis	Queensland University of Technology

This paper extends prior research on air traffic trajectory clustering by presenting a novel two-stage approach to overcome the constraints of conventional clustering algorithms, particularly when dealing with smaller datasets. In the first stage, clustering is performed using Procrustes analysis. Then, the second stage incorporates new trajectories into the resulting clusters. This integration is achieved by assessing the incoming data using the discrete Fréchet distance and adjusting the cluster deviation and track count parameters accordingly. Through this iterative process, a more precise and comprehensive representation of airspace is attained, resulting in enhanced clustering metrics. Moreover, a detailed examination of non-clustered trajectories using the Fréchet distance metric reveals sparse or shifted trajectories that exhibit minimal deviation from existing clusters. The proposed method demonstrates its efficacy by notably reducing the number of non-clustered trajectories while maintaining an acceptable level of increased deviation within clusters

compared to the original clustering algorithm. This refined model offers valuable insights into air traffic patterns and can be applied to various domains, including air traffic flow prediction, airspace optimisation, and facilitating the integration of UAVs into the airspace.

17:30-17:50	WeC4.4

Recent Trends on UAS-UTM Ecosystem and Integration Challenges, pp. 529-537

Singh, Govind	Technology Innovation Institute
Pashchapur, Ravi Ashok	Technology Innovation Institute
Ballal, Hrishikesh	Openskies Aerial Technology

Unmanned traffic management (UTM) is a critical component in the integration of unmanned aircraft systems (UAS) into the national airspace. As UAS operations continue to grow in scale and complexity, the development of a robust UTM ecosystem becomes essential to ensure the safety and security of the airspace. This survey aims to explore the current state of UTM technology, policies, and procedures, as well as the challenges and opportunities facing the UTM ecosystem. It will review the existing UTM architectures and frameworks, such as those developed by the Federal Aviation Administration (FAA) and the European Union's U-space initiative (U-SPACE) and evaluate their effectiveness in managing UAS operations. Furthermore, it will also examine the key UTM service providers and their offerings, including UAS traffic management systems (UTM systems), communication and navigation systems, and airspace management services. Additionally, it will explore the role of government agencies, UAS operators, and technology providers in the development and implementation of UTM solutions. Finally, we discuss V2X communication threats related to UTM. By providing a comprehensive overview of the current state of UTM, this study will contribute to a better understanding of the challenges and opportunities in the UTM ecosystem and inform the development of future UTM solutions.

17:50-18:10	WeC4.5

Airspace Advisory Service: Towards Detect and Avoid for UAS Operators Utilizing the Traffic Information Service, pp. 538-545

Jepsen, Jes Hundevadt	University of Southern Denmark
Eduardo-Teomitzi, Hugo	HHLA Sky
Törsleff, Sebastian	HHLA Sky GmbH
Jensen, Kjeld	University of Southern Denmark

In this paper, we propose a concept design for an Airspace Advisory Service (AAS), assisting UAS operators with Detect and Avoid capabilities during flight operations. The AAS utilizes the traffic information service from the U-space service providers. Based on adjacent air traffic, two risk indexes are introduced for each aircraft near the operating Unmanned Aerial Vehicle (UAV); 1) a Collision Risk Index, assessing the probability of the aircraft entering the UAV's Remain Well Clear volume, and 2) Intruder Risk Index, assessing the probability of the aircraft breaching the UAV's Operational Volume. Both risk indexes are fuzzy logic-based, and the calculation of them is presented using real flight data for two different flight scenarios. Moreover, the Traffic Advisory and Resolution Advisory principles from the TCAS concept are applied for each aircraft by calculating dynamic elliptical models based on their horizontal velocity and expected angular change of heading. A recommended advisory is determined for each aircraft and provided to the UAS operator for maintaining a safe operation.

The proposed concept design has been integrated into an existing ground control station software, named QGroundControl, as proof of concept. Input from experienced UAS operators, e.g. how to visually display relevant information for decision-making, have been included in the integration process. The comparison between QGroundControl with/without the AAS integrated shows the enhancement of situational awareness. Simulated air traffic has been used for validating the behavior of the AAS and for testing its CPU usage when processing up to 15 aircraft simultaneously. A higher CPU usage was observed but is not considered to have a significant influence on the overall CPU performance.

18:10-18:30	WeC4.6

Adjacent Airspace Risk and Containment Requirement Estimation for Uncrewed Operations, pp. 546-555

Mcfadyen, Aaron	Queensland University of Technology
Williams, Brendan	Boeing Defence Australia
Froes Silva, Guilherme	Queensland University of Technology

This paper considers the problem of quantifying air risk for adjacent airspace and estimating containment requirements for volumetrically constrained uncrewed operations. First, a quantitative air risk estimation framework linking operational and adjacent airspace collision risk subject to containment probability is presented. Second, continuous and discrete approaches to calculate adjacent airspace collision risk components within the framework are derived then used to estimate containment probability requirements given target safety levels. Third, case studies using advanced air risk estimation approaches, diverse air traffic environments, and hypothetical uncrewed operations are analysed. The results can help justify suitable quantitative containment requirements related to adjacent airspace risk. The work therefore provides mathematical rigor and real examples to support ongoing development of uncrewed system requirements and established operational risk assessment approaches

Technical Program for Thursday June 6

ThA1	MIKIS 1
Best Paper Award (Regular Session)	
Chair: Loianno, Giuseppe	New York University
Co-Chair: Vitzilaios, Nikolaos	University of South Carolina

10:30-10:50 ThA1.1

A Unified Inner-Outer Loop Reinforcement Learning Flight Controller for Fixed-Wing Aircraft, pp. 556-563

Chowdhury, Mozammal — University of Kansas
Keshmiri, Shawn — University of Kansas

One of the challenges with controlling autonomous aircraft is the coupling between the outer- and inner-loop control blocks, which becomes particularly pronounced when the aircraft executes aggressive maneuvers or experiences adverse onboard conditions such as motor or servo failures. The coupling between the outer- and inner-loop control blocks can cause phase shifts, sustained oscillations, and even lead to loss of control (LoC). To enhance safety and reliability in autonomous aircraft, a unified reinforcement learning (URL) longitudinal control framework has been developed for fixed-wing autonomous aircraft. This strategy replaces the cascaded outer- and inner-loop control blocks with a single inner-outer loop, which calculates the desired control commands (guidance) and executes them (control) in a single step. The structural design of URL enables the integration of fixed-wing aircraft dynamic constraints, such as stall angle of attack and maximum acceleration, as well as physical control constraints, like maximum control surface deflections. These constraints are often challenging to implement in many existing modern control methods. The URL controller robustness to modeling uncertainty is improved using a randomized training environment based on two different LTI models: a physics-based model and a model developed using the derivative-free cross-entropy (CEM) optimization algorithm and flight test data. The validation flight tests demonstrated the URL flight controller's superior performance in real-world environments with low to moderate wind conditions.

10:50-11:10 ThA1.2

On Dexterous Aerial and Ground Manipulation Using a Multi-Modal OmniRotor Platform Equipped with a Fast, Soft, Kirigami Gripper, pp. 564-571

Buzzatto, Joao — The University of Auckland
Liarokapis, Minas — The University of Auckland

Aerial grasping has many applications in the fields of search-and-rescue, maintenance, inspection, and the delivery industry. However, there are still many limitations to be overcome, including better and more lightweight gripper solutions, and more efficient payload transportation methods. Soft grippers offer the advantage of being lightweight, compliant, suitable for delicate objects, and requiring simple control. While soft robotic grippers have been explored for aerial grasping, the combination of fast grasping and soft grippers has not been demonstrated. Moreover, multi-modality for aerial grasping is under-explored in the literature. This paper presents a novel approach to aerial grasping using a Kirigami-based ultra-lightweight soft gripper with a fast actuation system and a hybrid, multi-modal OmniRotor vehicle. A platform belonging to the OmniRotor class, is a hybrid, multimodal vehicle that combines the advantages of Unmanned Aerial Vehicles (UAV) and Unmanned Ground Vehicles (UGV), being capable of continuous omnidirectional thrust vectoring and with both aerial and ground manipulation capabilities. This work demonstrates how Kirigami grippers can be used for aerial grasping, proposes the design of a spring-loaded, fast-release, lightweight actuation mechanism for the Kirigami gripper, and demonstrates how an OmniRotor platform can be used for efficient, single-platform aerial and ground manipulation in a construction environment. The contributions of this work can help overcome the limitations of aerial grasping and enable efficient multi-modal manipulation with unmanned vehicles.

11:10-11:30 ThA1.3

Experimental Validation of Sensitivity-Aware Trajectory Planning for a Quadrotor UAV under Parametric Uncertainty, pp. 572-578

Srour, Ali — IRISA/INRIA
Marcellini, Salvatore — University of Naples Federico II
Belvedere, Tommaso — Sapienza University of Rome
Cognetti, Marco — LAAS-CNRS
Franchi, Antonio — University of Twente
Robuffo Giordano, Paolo — IRISA / INRIA Rennes

In this work, we provide an experimental validation of the recent concepts of closed-loop state and input sensitivity in the context of robust flight control for a quadrotor (UAV) equipped with the popular PX4 controller. Our objective is to experimentally assess how the optimization of the reference trajectory w.r.t these sensitivity metrics can improve the closed-loop system performance against model uncertainties commonly affecting the quadrotor systems. To accomplish this, we present a series of experiments designed to validate our optimization approach on two distinct trajectories, with the primary aim of assessing its precision in guiding the quadrotor through the center of a window at relatively high speeds. This approach provides some interesting insights for increasing the closed-loop robustness of the robot state and inputs against physical parametric uncertainties that may degrade the system's performance.

11:30-11:50 ThA1.4

A Virtual Spring-Damper Approach for UAV Swarm Formation and Decentralised Collision Avoidance, pp. 579-585

Mejias Alvarez, Luis — Queensland University of Technology
Arias Perez, Pedro — Universidad Politecnica De Madrid
Javier, Melero Deza — Universidad Politecnica De Madrid

Campoy, Pascual — Universidad Politecnica Madrid

This paper introduces a method for controlling UAV swarm formations and avoiding collisions using the Virtual Spring-Damper (VSD) approach. This approach draws upon classical mechanical spring-damper systems, employing displacement and velocities to generate attractive and repulsive forces. These forces help sustain swarm formation and prevent collisions in a decentralized manner. Extensive simulations provided a systematic approach to obtain the parameters involved in the spring-damper system. Flight tests were carried out to verify the proposed method. The experimental outcomes align with our simulations, demonstrating effectiveness in collision avoidance while preserving a specified flight formation.

11:50-12:10 — ThA1.5

Phased Array Radio Navigation: UAV Field Tests During GNSS Jamming, pp. 586-593

Gryte, Kristoffer — Norwegian University of Science and Technology
Bryne, Torleiv Håland — Norwegian University of Science and Technology
Johansen, Tor Arne — Norwegian University of Science and Technology

Phased array radio systems (PARS) on the ground can determine the direction and range to uncrewed aerial vehicles (UAV) that it communicates with. By communicating the position back to the UAV, it can be used for navigation also in conditions when GNSS or other positioning systems are unavailable. In this paper we report field tests with fixed-wing UAV flights under actual GNSS jamming, where an inertial navigation system (INS) aided by both GNSS and PARS is tested. The experimental results show that uninterrupted stable flight is possible by switching between GNSS and PARS aiding. The results also show that reliable integrity monitoring of the GNSS and PARS are essential for resilient navigation when switching between GNSS and PARS, especially in conditions when the UAV fly outside the PARS frustum while GNSS is jammed.

12:10-12:30 — ThA1.6

FireFly Project: UAV Development for Distributed Sensing of Forest Fires, pp. 594-601

Puttapirat, Pargorn — Chiang Mai University
Woradit, Kampol — Chiang Mai University
Hesse, Henrik — University of Glasgow
Bhatia, Dinesh — RMIT University Vietnam

Forest fires pose significant threats to ecosystems and communities globally. This paper explores the development of an automated system for forest fire monitoring and prevention, particularly focusing on regions around Northern Thailand. Despite recent applications of Unmanned Aerial Vehicles (UAVs) for fire detection, existing technologies face challenges in detecting early onset of fires in dense forests due to limited resolution and sensitivity of thermal cameras. To address this, this paper proposes a novel approach combining UAV-based surveying with ground-based Internet of Things (IoT) sensors to enable early detection of forest fires, even when obscured by tree canopies. The low-cost IoT sensors measure temperature, humidity, and air quality at forest ground level. To overcome limitations in 4G communication for the IoT sensors, our system leverages UAVs as communication hubs to collect data from IoT sensors and survey the area for smoke and fire. The proposed system, part of the FireFly Project in collaboration with Chiang Mai University and the University of Glasgow, aims to overcome limitations of existing technologies and provide effective forest fire monitoring and prevention solutions. Experimental results presented in this paper demonstrate the performance of the distributed UAV-IoT system in detecting and communicating potential forest fires, paving the way for enhanced wildfire management strategies in fire-prone areas.

ThA2 — **MIKIS 2**

Aerial Robotic Manipulation (Regular Session)

Chair: Trujillo, Miguel Ángel — Center for Advanced Aerospace Technologies (CATEC)
Co-Chair: Gabellieri, Chiara — University of Twente

10:30-10:50 — ThA2.1

A Novel Unmanned Aerial System for Power Line Inspection and Maintenance Operations, pp. 602-609

Marredo, Juan Manuel — CATEC
Petrus, Ángel Luis — CATEC
Trujillo, Miguel Ángel — Center for Advanced Aerospace Technologies (CATEC)
Viguria, Antidio — FADA-CATEC
Ollero, Anibal — Universidad De Sevilla - Q-4118001-I

Ensuring the integrity and reliability of power lines is essential to maintain continuous service and avoid potential catastrophes. However, the increasingly extensive infrastructure represents formidable challenges in terms of inspection, maintenance, and worker safety. This paper presents the design, development, and experimental validation of the Main Local Manipulation Platform (MLMP), a versatile aerial manipulator designed to install and remove a wide variety of devices on power lines while perched, without interrupting the power. The paper outlines the main design considerations, challenges encountered, and solutions applied, including electrical protection, device manipulation and perching strategies. Multiple validation experiments, both in controlled and real scenarios, demonstrated the platform's effectiveness in the installation of clip-type bird diverters, cable separators and charging stations. The results underscore the potential of the MLMP to transform power line inspection and maintenance operations, improving the efficiency, reducing costs, and ensuring worker safety.

10:50-11:10 — ThA2.2

A Survey of Modeling and Control Approaches for Cooperative Aerial Manipulation, pp. 610-617

Barakou, Stamatina — National Technical University of Athens
Tzafestas, Costas — National Technical University of Athens

Valavanis, Kimon P. University of Denver

This survey centers around modeling and control approaches that reflect the state-of-the-art in quadrotor- and multirotor- based cooperative aerial manipulation. The research focus is on comparing and evaluating prototype systems and methods that have been implemented and tested, mostly, in real-time in diverse applications. By summarizing the state-of- the-art, the aim is to provide a comprehensive guide to researchers whose interest is in developing multirotor platforms for cooperative aerial manipulation.

11:10-11:30 ThA2.3

Increasing Repeatability of the Perching on Branch for Flapping-Wing Flying Robot, pp. 618-623

Rafee Nekoo, Saeed Escuela Técnica Superior De Ingeniería, Universidad De Sevilla
Sanchez-Laulhe, Ernesto University of Malaga
Gordillo Durán, Rodrigo Escuela Técnica Superior De Ingeniería, Universidad De Sevilla
Hernandez, Mario Escuela Técnica Superior De Ingeniería, Universidad De Sevilla
Ollero, Anibal Universidad De Sevilla - Q-4118001-I

The flapping-wing technology in aerial robotics proposes an alternative way of thrust and lift production rather than the use of high-speed rotary propellers. Those benefits come with the cost of a challenge in take-off and landing. Perching is a good way of landing, like real birds in nature; however, impact and slow flight close to perching are difficult tasks. The current flight control presents an average speed of 4(m/s) in the launching and flight, and a slight reduction to 2(m/s) close to perching, approximately. The recently published paper on the perching of flapping-wing flying robots on a branch, on the scale of big-bird size 1.5(m) wingspan, showed a repeatability of 66% [1]. The use of a laser line sensor for last-meter detection and direct actuation of the leg was used to follow the branch close to impact. Here in this work, several modifications have been done to increase the success rate: using feedback on the center-of-mass (CoM) of the robot bird, and the addition of a transformation between the CoM and end-effector of the claw. By this means the correction of the leg-claw position receives feedback from the motion capture system. So, by using more precise feedback and a control transformation, better reliability is expected. The white background for the line sensor is not necessary anymore which is another advantage of this proposed approach. The proposed method resulted in a more reliable way of flight, branch detection, and perching, increasing the repeatability percentage rate to 88.3%.

11:30-11:50 ThA2.4

Haptic-Based Bilateral Teleoperation of Aerial Manipulator for Extracting Wedged Object with Compensation of Human Reaction Time, pp. 624-630

Byun, Jeonghyun Seoul National University
Eom, Dohyun Seoul National University
Kim, H Jin Seoul National University

Bilateral teleoperation of an aerial manipulator facilitates the execution of industrial missions thanks to the combination of the aerial platform's maneuverability and the ability to conduct complex tasks with human supervision. Heretofore, research on such operations has focused on flying without any physical interaction or exerting a pushing force on a contact surface that does not involve abrupt changes in the interaction force. In this paper, we propose a human reaction time compensating haptic-based bilateral teleoperation strategy for an aerial manipulator extracting a wedged object from a static structure (i.e., plug-pulling), which incurs an abrupt decrease in the interaction force and causes additional difficulty for an aerial platform. A haptic device composed of a 4-degree-of-freedom robotic arm and a gripper is made for the teleoperation of aerial wedged object-extracting tasks, and a haptic-based teleoperation method to execute the aerial manipulator by the haptic device is introduced. We detect the extraction of the object by the estimation of the external force exerted on the aerial manipulator and generate reference trajectories for both the aerial manipulator and the haptic device after the extraction. As an example of the extraction of a wedged object, we conduct comparative plug-pulling experiments with a quadrotor-based aerial manipulator. The results validate that the proposed bilateral teleoperation method reduces the overshoot in the aerial manipulator's position and ensures fast recovery to its initial position after extracting the wedged object.

11:50-12:10 ThA2.5

Towards Instance Segmentation Based Litter Collection with Multi-Rotor Aerial Vehicle, pp. 631-637

Zoric, Filip University of Zagreb
Franchi, Antonio University of Twente
Orsag, Matko University of Zagreb
Kovacic, Zdenko University of Zagreb
Gabellieri, Chiara University of Twente

This paper presents a novel aerial robotics application of an instance segmentation based floating litter collection with a multirotor aerial vehicle (MRAV). In the scope of the paper, we present a review of the available datasets for litter detection and segmentation. The reviewed datasets are used to train Mask-RCNN neural network, for instance segmentation. Neural network is off board deployed on an edge computing device and used for litter position estimation. Based on the estimated litter position, we plan a path based on a quadratic Bezier curve for litter pick up. We compare different trajectory generation methods for object pick-up. The system was verified in a laboratory environment. In the end, we present practical considerations and improvements that are necessary to enable autonomous litter collection with MRAV.

12:10-12:30 ThA2.6

On the Existence of Static Equilibria of a Cable-Suspended Load with Non-Stopping Flying Carriers, pp. 638-644

Gabellieri, Chiara University of Twente
Franchi, Antonio University of Twente

This work answers positively the question whether non-stop flights are possible for maintaining constant the pose of cable-suspended objects. Such a counterintuitive answer paves the way for a paradigm shift where energetically efficient fixed-wing flying carriers can

replace the inefficient multirotor carriers that have been used so far in precise cooperative cable-suspended aerial manipulation. First, we show that one or two flying carriers alone cannot perform non-stop flights while maintaining a constant pose of the suspended object. Instead, we prove that three flying carriers can achieve this task provided that the orientation of the load at the equilibrium is such that the components of the cable forces that balance the external force (typically gravity) do not belong to the plane of the cable anchoring points on the load. Numerical tests are presented in support of the analytical results.

ThA3	KAM
Control Architectures (Regular Session)	
Chair: Castillo, Pedro	Université De Technologie De Compiègne
Co-Chair: Grijalva, Nicholas	New Mexico State University

10:30-10:50	ThA3.1

Distributed Model Predictive Control for Cooperative Multirotor Landing on Uncrewed Surface Vessel in Waves, pp. 645-651

Stephenson, Jess	Queen's University
Duncan, Nathan	Queen's University
Greeff, Melissa	Queen's University

Heterogeneous autonomous robot teams consisting of multirotor and uncrewed surface vessels (USVs) have the potential to enable various maritime applications, including advanced search-and-rescue operations. A critical requirement of these applications is the ability to land a multirotor on a USV for tasks such as recharging. This paper addresses the challenge of safely landing a multirotor on a cooperative USV in harsh open waters. To tackle this problem, we propose a novel sequential distributed model predictive control (MPC) scheme for cooperative multirotor-USV landing. Our approach combines standard tracking MPCs for the multirotor and USV with additional artificial intermediate goal locations. These artificial goals enable the robots to coordinate their cooperation without prior guidance. Each vehicle solves an individual optimization problem for both the artificial goal and an input that tracks it but only communicates the former to the other vehicle. The artificial goals are penalized by a suitable coupling cost. Furthermore, our proposed distributed MPC scheme utilizes a spatial-temporal wave model to coordinate in real-time a safer landing location and time the multirotor's landing to limit severe tilt of the USV.

10:50-11:10	ThA3.2

Vision-Based Algorithm for Autonomous Aerial Landing, pp. 652-657

Morando, Alessandra Elisa Sindi	UNIGE
Ferreira Santos, Marcone	Heudiasyc Laboratory UMR CNRS 7253 - Université De Technologie D
Castillo, Pedro	Université De Technologie De Compiègne
Correa Victorino, Alessandro	Heudiasyc Laboratory UMR CNRS 7253, Université De Technologie De

The landing phase is a critical stage in autonomous aerial landing, especially when the aerial vehicle lands on a moving platform, as ground vehicles. In this paper, a solution combining the information from the onboard camera of the drone with an observer is used to estimate and predict the future position of the landing platform. This landing estimation is used in the control algorithm, based on quaternions, for generating and tracking a landing trajectory. The proposed solution is then validated in real-time experiments (two scenarios) to demonstrate the well performance and efficiency of the closed-loop system. Main graphs from these experiments are reported in this paper. Moreover, as this work aims to set the base for future developments, existing limitations from this work are discussed in the last section

11:10-11:30	ThA3.3

Fast Trajectory Tracking for Commercial Off-The-Shelf UAS Using Model Predictive Control: Real-Time Implementation and Performance Analysis, pp. 658-665

Mirhajianmoghadam, Hengameh	New Mexico State University
Grijalva, Nicholas	New Mexico State University
Garcia Carrillo, Luis Rodolfo	New Mexico State University

Following swift changes in the waypoints of a trajectory is crucial for unmanned aerial systems (UASs). This capability allows UAS to quickly adapt to changing conditions and execute complex maneuvers with high accuracy, enhancing their effectiveness in various applications. Implementing trajectory tracking in real-time is challenging, even more so if the UAS is a Commercial off-the-shelf (COTS) platform. Model Predictive Control (MPC) is a potential solution for this scenario, however, the dynamic model of UAS is essential for proper functionality. Obtaining an exact model of a COTS UAS is often difficult, especially when dealing with platforms executing internal controllers on an embedded autopilot. To overcome this obstacle, our study implements a model identification process for the UAS, through processing input/output data pair collected during experimental flights. Using the identified model, the MPC optimizes the error between the system's current state and the desired reference trajectory over a finite horizon and calculates the appropriate control command while considering the system velocity constraints. The functionality of the tracking mechanism is demonstrated under two real-time trajectory tracking scenarios, a circle, and a rhodonea curve, executed at translational velocities close to the physical constraints of the UAS. The experimental evaluation of the proposed approach, focusing on accuracy and control performance, demonstrates the potential of the proposed solution for COTS UAS platforms.

11:30-11:50	ThA3.4

Low-Cost Monocular Vision-Based Localization and Feedback Control of UAS for Classroom and Education Settings, pp. 666-672

Grijalva, Nicholas	New Mexico State University

Mirhajianmoghadam, Hengameh	New Mexico State University
Garcia Carrillo, Luis Rodolfo	New Mexico State University

We introduce a cost-effective real-time 3-dimensional localization and control system to quad rotorcraft Unmanned Aircraft Systems (UASs). The intended purpose of the system is to be implemented in low-budget classrooms to teach real-time closed-loop control of UASs and expand interest in the field. The system's localization technique only requires light-emitting diode (LED) markers and a conventional webcam device. Relying on the sampled visual location data, a closed-loop feedback control is developed for real-time stabilization. The system can be implemented with less than 1% of the monetary cost of a conventional motion capture system (MCS), which allows more institutions to purchase and use the materials. To validate our approach, the positional data from the proposed localization system is compared with respect to ground truth data from a conventional MCS. Results from several real-time experiments are provided to validate the reliability and applicability of the localization system in UAS control.

11:50-12:10	ThA3.5

UAS 3D Path Following Guidance Method Via Lyapunov Control Functions, pp. 673-680

Xu, Jeffrey	University of Kansas
Keshmiri, Shawn	University of Kansas

This study explores the application of a comprehensive 3D guidance methodology, developed using control Lyapunov functions, in fixed-wing UAS with significant inertia. Initially, simplified inertia-free particles are utilized for control synthesis, followed by the reintroduction of aircraft dynamics to ensure effective path tracking. In a six-degree-of-freedom simulation environment, the 3D guidance law is compared with the widely adopted L_1 guidance method, demonstrating exponential convergence to the desired trajectory in both lateral and longitudinal frames. These findings highlight the adaptability and efficacy of control Lyapunov functions, showcasing comparable performance to guidance logics tailored specifically for aerial systems, thus offering promising prospects for precise path following in UAS applications

12:10-12:30	ThA3.6

Robust, Fiducial Markers Based Predictive Control Scheme for Infrastructure Inspection with Unmanned Aerial Vehicles, pp. 681-687

Lynch, Angus	The University of Auckland
Buzzatto, Joao	The University of Auckland
Liarokapis, Minas	The University of Auckland
Heshmati Alamdari, Shahab	Aalborg University

Over the last decades a lot of research effort has been put into the development of new Unmanned Aerial Vehicles (UAVs) and mobile robots for the inspection of critical infrastructure, such as bridges, roads, and dams, in remote locations or dangerous conditions. But despite the increased interest, the application of such autonomous platforms is hindered by the lack of sufficiently accurate localisation methods, especially in GPS-denied environments. Employing fiducial markers to aid such a localisation is an efficient solution that necessitates the use of subsidiary control laws that will allow the autonomous platform to attain a predefined, desired pose with respect to the marker of interest for localisation purposes. In this paper, we utilize Nonlinear Model Predictive Control (NMPC) in a vision-based framework to accurately control a drone in proximity to its target. This approach considers the Field of View (FoV) constraints, control input saturation, uncertainties, and external disturbances during the control design phase. Furthermore, the stability and convergence of the closed-loop cascade system have been examined. The efficacy and robustness of the proposed vision-based control strategy are validated through real-time experiments on a compact, custom-build UAV platform.

ThA4	**DILOVO**
Swarms I (Regular Session)	
Chair: Rastgoftar, Hossein	University of Arizona
Co-Chair: Boubin, Jayson	Binghamton University

10:30-10:50	ThA4.1

Online B-Spline Based Trajectory Planning for Swarm of Agents Using Distributed Model Predictive Control, pp. 688-694

Dinh, Cong Khanh	Univ. Grenoble Alpes, Grenoble INP, LCIS
Prodan, Ionela	Grenoble INP, Univ. Grenoble Alpes
Stoican, Florin	Politehnica University of Bucharest

This paper deals with the motion planning in real-time for swarm of agents using distributed Model Predictive Control (DMPC). Optimization-based control helps both to stabilize the motion dynamics of the robots and to enforce the system's constraints. However, the price is a significant increase in complexity as the scale of the system surges. To improve the scalability for a large formation, we propose a DMPC framework that considers B-spline parameterizations for the agents' trajectories. The proposed approach has great promise for multi-drone systems, as illustrated with simulation examples using a state-of-the-art quadcopter model.

10:50-11:10	ThA4.2

Fluid Flow Modeling and Experimental Evaluation of Unscrewed Aerial System Coordination, pp. 695-702

Uppaluru, Harshvardhan	University of Arizona
Ghufran, Mohammad	University of Arizona
Rastgoftar, Hossein	University of Arizona

Reliability is a critical aspect of multi-agent system coordination as it guarantees the system's accurate and consistent functionality. If one agent in the system fails or behaves unexpectedly, it can negatively impact the performance and effectiveness of the entire system.

Therefore, it is important to design and implement multi-agent systems with a high level of reliability to ensure that they can operate safely and move smoothly in the presence of unforeseen agent failure or lack of communication with some agent teams moving in a shared motion space. This paper presents a novel navigation model that, in an ideal fluid flow, divides agents into cooperative (non-singular) and noncooperative (singular) agents, with cooperative agents sliding along streamlines safely enclosing non-cooperative agents in a shared motion space. A series of flight experiments utilizing crazyflie quadcopters will experimentally validate the suggested model.

11:10-11:30	ThA4.3

Dynamic Decentralized 3D Urban Coverage and Patrol with UAVs, pp. 703-710

Leong, Wai Lun	National University of Singapore
Cao, Jiawei	National University of Singapore
Teo, Rodney	National University of Singapore

In the event of natural or man-made disasters in an urban environment, such as fires, floods, and earthquakes, a swarm of unmanned aerial vehicles (UAVs) can rapidly sweep and provide coverage to monitor the area of interest and locate survivors. We propose a modular framework and patrol strategy that enables a swarm of UAVs to perform cooperative and periodic coverage in such scenarios. Our approach first discretizes the area of interest into viewpoints connected via closed paths. UAVs are assigned to teams via task allocation to cooperatively patrol these closed paths. We propose a minimal, scalable, and robust patrol strategy where UAVs within a team move in a random direction along their assigned closed path and "bounce" off each other when they meet. Our simulation results show that such a minimal strategy can exhibit an emergent behaviour that provides periodic and complete coverage in a 3D urban environment.

11:30-11:50	ThA4.4

Tsunami: Scalable, Fault Tolerant Coverage Path Planning for UAV Swarms, pp. 711-717

Boubin, Jayson	Binghamton University
Szklany, Matthew	Binghamton University
Cohen, Adam	Binghamton University

Unmanned Aerial Vehicles are powerful robotic tools capable of quickly sensing vast areas. Their maneuverability and speed suit them to sensing tasks in diverse domains including agriculture, search and rescue, infrastructure inspection, and ecology. Piloting these missions, however, is expensive, time consuming, and requires expertise. Furthermore, environments for sensing can be large, necessitating swarms of UAV for timely scouting. Waypoint-based automated collection systems have existed for over a decade, but rarely account for the complexities of UAV swarms, including faults regularly experienced on long deployments. In this paper, we introduce Tsunami, a novel system for UAV swarm data collection. Tsunami dynamically partitions environments, avoids aerial collisions, and responds to changes in swarm size over the course of long missions due to battery discharges and faults. Through a simulated agricultural case study, we show that Tsunami is efficient, fault tolerant, and improves data capture time by 1.6-1.91X when compared to state-of-the-art coverage path planning algorithms.

11:50-12:10	ThA4.5

A Dynamic Area Approximation-Based Stochastic Multi-UAV Target Search with Noisy Measurements, pp. 718-723

Puthumanaillam, Gokul	Manipal Institute of Technology
Kandath, Harikumar	International Institute of Information Technology
Senthilnath, J	Institute for Infocomm Research, A*STAR

This paper presents a novel approach to effectively search for a target using a multi-robot system. The proposed approach augments the conventional swarm-based stochastic search algorithms by dynamically refining the search space to locate the source. Compared to other search algorithms, including PSO, Cuckoo Search Algorithm, Bat Algorithm, Glowworm Swarm Optimization and Random Walk, our algorithm reduces the time taken, and the amount of exploration done is much more succinct. Similarly, the algorithm makes no concessions in terms of success rate. In extreme scenarios, when the number of particles is fewer than five, the search space is enormous, or the search space is unbounded or noise in the sensor readings, our method stands out and performs far better than other stochastic search methods.

12:10-12:30	ThA4.6

Communication-Free Formation Flight Control for Autonomous Fixed-Wing UAVs in GNSS-Denied Environments, pp. 724-731

Mata, León	GMV Aerospace and Defence
García Insa, Laura	GMV Aerospace and Defence

This article presents a novel formation control strategy for a group of fixed-wing unmanned aerial vehicles (UAVs) in GNSS-denied environments without communication links. Each aircraft will only have access to the relative states measured using its onboard sensors and to an alternative source of absolute navigation. The presented approach is based on a controller which is a function of the state estimation error, allowing the aircraft with high accuracy data to have a greater contribution to the formation guidance and reducing the effect of those with less precise information. The approach has been tested in a simulation environment over a series of scenarios including different sensors and configurations, showing that the proposed control strategy allows to reduce the deviation with respect to the nominal path in the presence of process noise and data uncertainties.

ThB1	**MIKIS 1**
LATAM Best Paper Award (Regular Session)	
Chair: Kim, H Jin	Seoul National University
Co-Chair: Brandao, Alexandre Santos	Federal University of Vicosa

15:20-15:40	ThB1.1

Dual Quaternion-Based Control for a Leader-Follower Formation of Two Quadrotors, pp. 732-739

Marciano, Harrison	Federal University of Espirito Santo
Villa, Daniel Khede Dourado	Federal University of Espírito Santo
Sarcinelli-Filho, Mário	Federal University of Espirito Santo
Giribet, Juan Ignacio	University of San Andrés

This paper investigates the use of dual quaternions for controlling a leader-follower configuration of small Unmanned Aerial Vehicles (UAVs). The paper focuses on how the parameters of a non-linear kinematic control algorithm can be chosen to achieve a prescribed behavior. The paper provides theoretical support, refines existing methods, and validates results through experiments. The findings contribute to the understanding and optimization of dual quaternion-based control strategies for small UAVs formations.

15:40-16:00	ThB1.2

Multiple Formations Control Using Distinct Virtual Structures, pp. 740-747

Bacheti, Vinícius Pacheco	Federal University of Espirito Santo
Brandao, Alexandre Santos	Federal University of Vicosa
Castillo, Pedro	Université De Technologie De Compiègne
Lozano, Rogelio	Université De Technologie De Compiègne
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

This paper addresses the problem of controlling two distinct formations of robots interacting with one another. To do that, two different approaches for a line structure are defined and a controller based on virtual structures is used, as well as a low-level controller in order to compensate for the dynamics of each robot. Tying both controllers is a multilayer structure responsible for the overall control. Simulations and experiments show the controllers working with different levels of complexity and help validate the proposed method.

16:00-16:20	ThB1.3

Using LQG Control As the Inner Loop Controller in Quadrotor Navigation, pp. 748-754

Tavares, Luiz	Universidade Federal Do Espirito Santo
Cordeiro, Rafael	Instituto Superior Técnico
Sarcinelli-Filho, Mário	Federal University of Espirito Santo
Villa, Daniel Khede Dourado	Federal University of Espírito Santo

LQG (linear Quadratic Gaussian) control is an optimizing control technique able to consider the noise included in the control input and in the output measurement as well. In this paper it is discussed its usage to close the inner control loop of an inner-outer control scheme applied to a quadrotor. The focus is to show that such a controller is efficient in dealing with measurement noise, which degrades the feedback quality, thus affecting the performance of the control system. The proposed control structure adopts an outer control loop based on the inverse kinematics, which produces velocity references for position control, and an inner control loop based on LQG, which controls the attitude and thrust of the vehicle, ensuring that the vehicle velocity converges asymptotically to the velocity reference while keeping the control signals within physical constraints. Experimental results of applying such a control structure to a micro aerial vehicle, Crazyflie 2.1, are presented and discussed, which validate the proposed control system.

16:20-16:40	ThB1.4

Exploring the Science and Art of UAV Light Painting: From Equations and Pixels to Long-Exposure Photography, pp. 755-762

Alves Fagundes Junior, Leonardo	Universidade Federal De Viçosa
Oliveira Barcelos, Celso	Federal University of Viçosa
Vassallo, Raquel	Federal University of Espirito Santo
Brandao, Alexandre Santos	Federal University of Vicosa

The use of Unmanned Aerial Vehicles (in short, UAVs, aka drones) for cultural and entertainment purposes, such as drone light shows, has grown exponentially. One such innovative and creative application is the visual arts using drones to explore long-exposure photography. Light painting is generally performed indoors and outdoors in a dedicated space with a human using a moving light source to create spectacular images and save the movement perception in a picture. In this work, we propose a robotic perception system designed to choreograph UAV movements based on time-parametric curves or image edges, serving as reference motions. Our framework begins by processing a digital image, extracting its contours through boundary tracing, and subsequently generating a safe, navigable, and precise path for UAV motion planning. This process involves optimizing waypoints within the UAV workspace to determine a feasible trajectory that encompasses all designated points or computes safe trajectories utilizing established mathematical equations. The validation of the motion planning is performed through light painting, where the UAV can either fly through the motion reference to mimic the original image. The generated trajectories on light painting mode by physical robots are compared against the ground-truth demonstrating the accuracy of the applied control scheme.

16:40-17:00	ThB1.5

A Systematic Literature Mapping of Path Planning and Collision Avoidance Approaches for Unmanned Fixed-Wings, pp. 763-770

Freitas, Elias José de Rezende	Universidade Federal De Minas Gerais, UFMG
Weiss Cohen, Miri	Braude Collège of Engineering
Guimarães, Frederico G.	Federal University of Minas Gerais
Pimenta, Luciano Cunha de Araújo	Universidade Federal De Minas Gerais

In the rapidly evolving world of Unmanned Aerial Vehicles (UAVs), fixed-wing aircraft stand out for their remarkable efficiency and long-range endurance. The path planning and collision avoidance approaches for these UAVs must also consider other constraints, such as the maximum curvature and pitch/climb angle, which are different from quadrotor drones. This paper presents systematic literature mapping (SLM) in this context, which provides an overview of path planning and collision avoidance approaches developed for fixed wing unmanned aerial vehicles in the last decade. Using Scopus and Web of Science databases, we extracted and analyzed data using the PICOC framework (Population, Intervention, Comparison, Outcome, and Context). Based on our inclusion and exclusion criteria, we identified 345 relevant articles for review. We applied an unsupervised classifier to cluster these approaches into domains systematically. This aims to highlight key topics, publication venues, and insights into the challenges and opportunities associated with path planning and collision avoidance for autonomous fixed-wing aircraft.

ThB2	**MIKIS 2**
Micro and Mini UAS (Regular Session)	
Chair: Castillo, Pedro	Université De Technologie De Compiègne
Co-Chair: Guerreiro, Bruno J. N.	NOVA School of Science and Technology

15:20-15:40	ThB2.1

In-Flight Capture Maneuver of Drones Using Model Predictive Control, pp. 771-778

Oliveira, Diogo N.	NOVA School of Science and Technology, FCT NOVA
Guerreiro, Bruno J. N.	NOVA School of Science and Technology

This paper presents a model predictive control (MPC) strategy to enable a rotary-wing shuttle drone to cooperatively capture a fixed-wing target drone during flight and place it in the ground safely. Simplified models of the two types of drones are presented, along with simple controllers for each vehicle. The developed strategy defines a simple nonlinear MPC problem that models the relative dynamics between the two drones, enabling the capture maneuver without a preassigned trajectory or rendezvous point. Simulation results demonstrate the capabilities of the proposed cooperative capture strategy, whereas experimental trials with a real shuttle and a simulated target validate the hardware and software integration of the developed system, showing promising performance.

15:40-16:00	ThB2.2

Modelling and Hovering Stabilisation of a Free-Rotating Wing UAV, pp. 779-785

Sansou, Florian	ENAC
Hattenberger, Gautier	ENAC
Zaccarian, Luca	--
Demourant, Fabrice	ONERA-CERT
Loquen, Thomas	ONERA

We propose a multibody model of a freewing UAV. This model allows obtaining simulations of the UAV's behaviour and, in the future, to design a control law stabilising the entire flight envelope (hovering and forward flight). We also describe the realisation of a prototype and a comparison of possible methods for estimating the UAV's states. With this prototype, we report on experimental hovering flights with a non-linear incremental dynamic inversion controller to stabilise the wing and a proportional derivative controller for the fuselage stabilization.

16:00-16:20	ThB2.3

Hybrid Locomotive Behaviors for an Amphibious Fixed-Wing / VTOL Tiltrotor UAV, pp. 786-791

Carlson, Stephen	University of Nevada, Reno
Papachristos, Christos	University of Nevada Reno

The theory and implementation of a set of alternate auxiliary locomotion modes are presented for an amphibious fixed-wing VTOL UAV. In real-world conditions and unstructured environments, the ability for the vehicle to employ alternative modes of locomotion is essential. By using tilting propulsor nacelles for thrust vectoring, the aircraft can taxi, or ferry, on the water surface. The VTOL tail motor is used for self-righting when the vehicle is unintentionally overturned. Equivalent comparisons to wheeled-robot maneuverability and controllability are provided. A set of experimental demonstrations are conducted, including an alternative to normal flight by using ground-effect for improved power efficiency.

16:20-16:40	ThB2.4

UAV-Based Foliage Plant Species Classification for Semantic Characterization of Pre-Fire Landscapes, pp. 792-799

Arora, Prateek	University of Nevada, Reno
Alcolea Vila, Pau	Worcester Polytechnic Institute
Borghese, Aiden	University of Nevada, Reno
Carlson, Stephen	University of Nevada, Reno
Feil-Seifer, David	University of Nevada, Reno
Papachristos, Christos	University of Nevada Reno

In this work we deal with the problem of establishing a system architecture to facilitate the real-time autonomous volumetric mapping alongside the semantic characterization of sagebrush ecosystem landscapes, to support the pre-fire modeling and analysis required to plan for wildfire prevention and/or suppression. The world, and more specifically the broader region of N. Nevada has been facing one of its most challenging periods over the course of the last decade, as far as uncontrolled wildfires are concerned. This has led to the development of research initiatives aimed at the ecosystem-specific modeling of the pre-, during-, and post-fire process effects to better understand, predict, and address these phenomena. However, to collect the required wide-field information that contains both centimeter-

level volumetric mapping fidelity, as well as semantic details related to plant (sub)-species, which for the common case of sagebrush can only be identified based on close-up inspection of their foliage fine structure, satellite photography remains insufficient. To this end, we propose a perception and mapping architecture of an aerial robotic system that is capable of: a) LiDAR-based centimeter-level reconstruction, b) robust multi-modal sensor fusion Simultaneous Localization and Mapping (SLAM) leveraging LiDAR, IMU, Visual-Inertial Odometry, and Differential GPS in a global optimization mapping framework, as well as c) a gimbal-driven point-zoom camera for the efficient real-time collection of close-up imagery of foliage pertaining to specific target plants, in order to allow their real-time identification based on their leaf micro-structure, by leveraging Deep-Learned classification deployed on a Neural Processing Unit.

16:40-17:00	ThB2.5

A Design Modification of a Quadrotor Frame Based on Fused Deposition Modeling, pp. 800-806

Jimenez-Flores, Alejandro	CIIIA-FIME-UANL
Tellez-Belkotosky, Pablo A.	CIIIA-FIME-UANL
Ollervides Vazquez, Edmundo Javier	CIIIA-FIME-UANL; TecNM-Instituto Tecnologico De La Laguna
Castillo, Pedro	Université De Technologie De Compiègne
Reyes Osorio, Luis Arturo	CIIIA-FIME-UANL
Garcia Salazar, Octavio	CIIIA-FIME-UANL

Quadrotor UAVs have mass variations in their performance and cost, or these are made of materials such as carbon fiber, which implies a higher manufacturing cost. Therefore, an alternative is to resort to manufacturing parts using 3D printing to reduce the mass and improve strength of materials. This work focuses on the structural analysis of a quadrotor UAV previously manufactured using 3D printing technology with polylactic acid (PLA) filament as an alternative to higher cost materials. Buckling problems are presented in the original design of the frame, so its design is reinforced by considerably increasing the mass. The main objective is to reduce the mass without compromising the structural integrity. Experimental tensile tests are performed on PLA specimens to determine their mechanical properties, as well as rotor thrust tests to evaluate the maximum loads on the frame. Three frame alternatives are proposed and designed, with the second proposal being the most successful, with a 41% reduction in mass. The structural simulation shows that this proposal complies with the structural limits of the aircraft, highlighting the feasibility of using PLA and optimizing designs using the finite element technique to reduce mass without compromising strength, representing an economical and efficient option in terms of aeronautical engineering.

ThB3	**KAM**

Aerial Vehicles for Hazardous Applications: From Environmental Sensing to Operations in Extreme Environments (Invited Session)

Chair: Sutera, Giuseppe	University of Catania
Co-Chair: Loianno, Giuseppe	New York University
Organizer: Guastella, Dario Calogero	University of Catania
Organizer: Sutera, Giuseppe	University of Catania
Organizer: Caballero, Alvaro	University of Seville
Organizer: Stoudek, Pavel	Czech Technical University in Prague

15:20-15:40	ThB3.1

Visual Environment Assessment for Safe Autonomous Quadrotor Landing (I), pp. 807-813

Secchiero, Mattia	New York University
Zhou, Yang	New York University
Nishanth, Bobbili	New York University
Loianno, Giuseppe	New York University

Autonomous identification and evaluation of safe landing zones are of paramount importance for ensuring the safety and effectiveness of aerial robots in the event of system failures, low battery, or the successful completion of specific tasks. In this paper, we present a novel approach for detection and assessment of potential landing sites for safe quadrotor landing. Our solution efficiently integrates 2D and 3D environmental information, eliminating the need for external aids such as GPS and computationally intensive elevation maps. The proposed pipeline combines semantic data derived from a Neural Network (NN), to extract environmental features, with geometric data obtained from a disparity map, to extract critical geometric attributes such as slope, flatness, and roughness. We define several cost metrics based on these attributes to evaluate safety, stability, and suitability of regions in the environment and identify the most suitable landing area. Our approach runs in real-time on quadrotors equipped with limited computational capabilities. Experimental results conducted in diverse environments demonstrate that the proposed method can effectively assess and identify suitable landing areas, enabling the safe and autonomous landing of a quadrotor.

15:40-16:00	ThB3.2

Experimental System Design of an Active Fault-Tolerant Quadrotor (I), pp. 814-821

Yeom, Jennifer	New York University
Thalaivirithan Margabandu Balakrishnan, Roshan Balu	New York University
Li, Guanrui	New York University
Loianno, Giuseppe	New York University

Quadrotors have gained popularity over the last decade, aiding humans in complex tasks such as search and rescue, mapping, and exploration. Despite their mechanical simplicity and versatility compared to other types of aerial vehicles, they remain vulnerable to rotor failures. In this paper, we propose an algorithmic and mechanical approach to addressing the quadrotor fault-tolerant problem in case of

rotor failures. First, we present a fault-tolerant detection and control scheme that includes various attitude error metrics. The scheme transitions to a fault-tolerant control mode by surrendering the yaw control. Subsequently, to ensure compatibility with platform sensing constraints, we investigate the relationship between variations in robot rotational drag, achieved through a modular mechanical design appendage, resulting in yaw rates within sensor limits. This analysis offers a platform agnostic framework for designing more reliable and robust quadrotors in the event of rotor failures. Extensive experimental results validate the proposed approach providing insights into successfully designing a cost-effective quadrotor capable of fault-tolerant control. The overall design enhances safety in scenarios of faulty rotors, without the need for additional sensors or computational resources.

16:00-16:20	ThB3.3

Drone-Assisted Remote Gas Sensing in Volcanic Scenarios (I), pp. 822-828

Guastella, Dario Calogero	University of Catania
Sutera, Giuseppe	University of Catania
Giudice, Gaetano	Istituto Nazionale Di Geofisica E Vulcanologia-Osservatorio Etne
Longo, Domenico	University of Catania
Muscato, Giovanni	University of Catania

The study of volcanoes is of primary importance due to the great impact that eruptions can have on the economy, safety, air traffic, and several other human activities. A main indicator of volcanic activities, crucial to predicting events, is based on the analysis of gases emitted from a volcano's vents. Acquisition of gas samples is, however, challenging due to extreme working conditions and safety precautions. A further challenge is also locating and relocating volcanic gas measurement devices, as plume density and direction can quickly change. In this paper, we propose to use an open-path gas analyzer mounted on a Pan-Tilt Unit that tracks a multirotor equipped with suitable mirrors. This allows to autonomously perform gas measurement missions in volcanic environments via Tunable Diode Laser Absorption Spectroscopy. The great advantage brought by such a multirotor-based approach is the rapid and accurate measurement of gases, which makes monitoring and prediction activities safer, timely, and cost-effective. The effectiveness and accuracy of the proposed approach has been tested in a real application.

16:20-16:40	ThB3.4

Aerial-Aquatic Robots As a New Paradigm for Blue Carbon Monitoring and Sequestration (I), pp. 829-834

Nguyen, Pham	EMPA/Imperial College London
Kovac, Mirko	Imperial College London

The relentless rise of the global atmospheric carbon dioxide levels emphasizes the need for novel and innovative approaches to carbon sequestration strategies. This paper highlights how natural carbon dioxide removal methods can integrate with novel robotic technologies to tackle carbon sequestration and biodiversity monitoring. We focus on the use of multi-modal aerial robotic systems, such as aerial-aquatic robots to enhance CDR efforts in Blue Carbon ecosystems. Since this ecosystem features the highest carbon sequestration per area in the natural environment, and straddles both land and sea, we see the potential in utilizing multi-modal robots as scalable solutions in these ecosystems. So far, research in these regions has been limited to satellite imagery, aerial photography, and manual sample collection and biomass measurement by individuals. This presents a substantial opportunity for robots to contribute to monitoring beneath the canopy, the soil, and underwater, and possibly even in the sequestration of CO2, alongside gathering other abiotic and biotic data, including information on plant and animal life. We view this as the inception of a robotics initiative focused on the blue carbon sector, aimed at aiding, and safeguarding these diminishing ecosystems and their inhabitants.

16:40-17:00	ThB3.5

A Multi-UAV Route Planning Method for Fast Inspection of Electric Power Transmission Lines (I), pp. 835-842

Caballero, Alvaro	University of Seville
Román Escorza, Francisco Javier	University of Seville
Maza, Ivan	Universidad De Sevilla
Ollero, Anibal	AICIA. G41099946

Electric power transmission lines are essential assets, and their maintenance is crucial to ensure a reliable service to society. However, with thousands of kilometers along the geography of any country, their inspection is costly and time-consuming. This paper proposes a route planning method for the fast inspection of power grids using a heterogeneous team of UAVs (Unmanned Aerial Vehicles). Given a power grid, the planning method, formulated as a vehicle routing problem, minimizes the mission time that the multi-UAV team needs to visually inspect the entire grid. The method integrates models of energy consumption and considers the existence of recharging stations where aerial robots can recharge their batteries for long-term operation. Moreover, a clustering strategy is also presented to reduce the computational burden of the planning problem without compromising the quality of the solutions. The performance of the resulting approach is analyzed in simulation under different conditions that show the benefits. Finally, experimental results in the Doñana National Park (Spain) showcase the validity of the planning method for real-world applications.

ThB4	**DILOVO**
UAS Reliability, Safety and Risk Assessment (Invited Session)	
Chair: Primatesta, Stefano	Politecnico Di Torino
Co-Chair: Bertrand, Sylvain	ONERA
Organizer: Primatesta, Stefano	Politecnico Di Torino
Organizer: Bertrand, Sylvain	ONERA

15:20-15:40	ThB4.1

Flying Is for Droids: A Survey of Research into Generating Certification Evidence for AI/ML Algorithms to Replace Human Pilots (I), pp. 843-849

Costello, Donald	USNA
Xu, Huan	University of Maryland

While academia and industry have shown that they can develop systems that exhibit high levels of autonomy across multiple domains (air, sea, and land systems), as of now, regulations do not exist to allow a system to operate autonomously (without a human in or on the loop to ultimately be accountable for the actions of the system). Without these regulations, a truly autonomous system will remain a demonstration program or simply science fiction. The United States Navy has publicly announced that it intends to dramatically increase its fleet of uncrewed aerial systems. To support an ongoing effort for fielding autonomy, researchers have been trying to define the problem and identify possible solutions. This survey paper details the work that has gone into generating certification evidence for artificial intelligence/machine learning algorithms to replace humans within naval aviation. It is hoped that the lessons learned, and standards developed can be used to spread autonomous functionality to other domains.

15:40-16:00	ThB4.2

Handling Ground Risks for Road Networks in UAS Specific Operations Risk Assessment (SORA) (I), pp. 850-857

Bertrand, Sylvain	ONERA
Raballand, Nicolas	ONERA
Lala, Stephanie	ONERA

This paper proposes a modification to the Specific Operations Risk Assessment (SORA) process to explicitly account for risks wrt. vehicles on road networks, in addition to risks wrt. people, in the determination of a Ground Risk Class for the UAS operation. The definition of a new risk index, the Road Risk Class (RRC), is proposed and expressions for its computation are given. Following the methodology of the actual SORA, these expressions are used to pre-compute a numeric table helping in the determination of the RRC from the UAS characteristics and road traffic data. The proposed risk assessment process is illustrated on an example of long-range mission with a fixed-wing UAV.

16:00-16:20	ThB4.3

Safety Barrier Diagrams for Specific Operations of Drones (I), pp. 858-864

Bieber, Pierre	ONERA
Delmas, Kevin	ONERA
Le Blaye, Patrick	ONERA
Pizziol, Sergio	ONERA
Prosvirnova, Tatiana	ONERA
Seguin, Christel	ONERA

We performed risk assessment to support BVLOS flight authorization with several drone manufacturers. We found out that, although technical aspects of drone designs were often unique, several operational aspects were very similar. Operational safety barriers (such as Return To Home or Flight Interruption) used to manage risks do not differ a lot. Furthermore, we also found out that it was not easy for drone manufacturers to provide a precise description of the policy used to manage risks.

In this paper, we propose a graphical notation that formalizes a safety policy and its safety barriers. We explore how to use Safety Barrier Diagrams (SBD) to support risk assessment activities, in particular the Functional Hazard Assessment (FHA).

16:20-16:40	ThB4.4

A 2.5D Risk-Aware Path Planning Method for Safe UAS Operations in Populated Environments (I), pp. 865-872

Primatesta, Stefano	Politecnico Di Torino

The increasing use of Unmanned Aircraft Systems (UAS) in Urban Air Mobility highlights the critical need to create safe urban air corridors. In this paper, we present a novel 2.5D risk-aware path planning strategy with the aim of computing safe routes for UAS in urban areas. The proposed approach uses 2.5D risk maps to assess the risk to the population on the ground caused by UAS operations. Specifically, the 2.5D risk map consists of a multi-layer structure discretizing the flight altitude and providing a simplified representation of the three-dimensional space. Thus, a 2.5D risk-aware path planning searches for the minimum risk path in the 2.5D risk map. The adopted risk-aware path planning is based on the well-known RRT* algorithm with the minimization of the overall risk in the risk map and the flight time. Furthermore, an energy-aware factor is also included in the cost function to obtain a more energy-efficient solution, avoiding excessive changes in altitude. The simulation results obtained considering a real-world scenario corroborate the proposed strategy. The combined use of 2.5D risk maps with a risk-aware path planning algorithm provides a promising solution for computing safe and energy-efficient routes in urban areas.

16:40-17:00	ThB4.5

UAS Procedures Model with System Architecture for Safety Analysis (I), pp. 873-880

Mathou, Charles	ISAE-SUPAERO
Delmas, Kevin	ONERA
de Saqui-Sannes, Pierre	ISAE-SUPAERO
Chaudemar, Jean-Charles	Isae - Disc

As the number of unmanned aerial systems (UAS) keeps increasing, so do the safety risks they pose. One way of maintaining an acceptable risk level is that operational procedures are adequately designed and proven. Model-based approaches involve modeling procedures as a sequence of tasks with inputs and outputs. These tasks abstract away the complexity of the subsystem or actor who performs them. However, UAS procedures typically involve multiple actors and subsystems, each of which contributes to the risk of the operation. Accounting for these heterogeneous risk contributors allows new failure propagation paths to be revealed, understood, and patched, leading to increased safety. To achieve this, we propose a methodology to connect the safety models of such contributors to our previous procedure models. We discuss and illustrate this methodology on a medium-sized fixed-wing UAV. We connect our procedure models to the UAV's functional architecture model and use them to generate minimal sequences leading to a crash of the UAV. New sequences illustrating the contribution of the UAV's architecture have been revealed that did not appear in our previous work on UAS procedures. This provides an opportunity to explore the contribution of the system's architecture to its overall safety through the procedures.

ThPo1	**MIKIS Foyer**
Poster Session I (Poster Session)	
Chair: Tsourveloudis, Nikos	Technical University of Crete

17:00-17:40	ThPo1.1

Autonomous Navigation in Dynamic Maze Environments under Adversarial Sensor Attack, pp. 881-886

Wisniewski, Mariusz	Cranfield University
Ona, Inigo	Cranfield University
Chatzithanos, Paraskevas	Cranfield University
Guo, Weisi	Cranfield University
Tsourdos, Antonios	Cranfield University

Autonomous navigation of complex and dynamically changing environments is challenging, but when the sensors that determine observables is unreliable, reliability is undermined. Current research largely focuses on either efficient navigation with reliable sensors, or sensor fusion mechanisms to offer robust position estimation. In many sensor fusion cases, it assumes that there is a regular structure to the environment (e.g., road or cityscape) or that the attacks are intermittent, and hence leverages on Kalman filters or alternative sensors as a holding fusion mechanism.

Here, we present work on reliable UAS navigation under adversarial sensor attack (e.g., persistent wide area or target following attacks) in irregular environments (e.g., a dynamic maze). We cannot rely on regularized routes in training, nor can we rely on a holding fusion algorithm to wait out an attack whilst simply estimating the next position in a smooth trajectory. The autonomous platform in our work needs to make rapid assessments and manoeuvres in the maze to reach its goal. In this work, we present initial findings on the effect of two types of attack on a reinforcement learning (RL) controlled drone: (1) a laser attack on the camera sensor, and (2) an area of effect denial attack on the lidar. We develop Variational autoencoder (VAE) based sensor filtering approaches to detect the effect of attacks with 95% success and assist in achieving robust navigation.

17:00-17:40	ThPo1.2

Optimizing Drone Operator Workload in the Terminal Area for Shipboard Operations, pp. 887-892

Bostock, Nick	USNA
Richez, Adrien	United States Naval Academy
Wickramasuriya, Maneesha	George Washington University
Webster-Giddings, Allison	American University of Iraq
Costello, Donald	USNA

The United States Navy (USN) is heavily reliant on its ability to operate aircraft in the maritime environment. Done successfully, shipboard flight operations allow air-capable ships to act as mobile airfields, ensuring the USN's ability to maintain freedom of the seas. Typically, rotary-wing aircraft land at the stern of USN surface vessels (i.e., a guided missile destroyer (DDG)). Ship movement creates turbulence induced by its superstructure, which may produce unfavorable conditions for rotary-wing aircraft just after takeoff and just before recovery. This ship-aircraft interplay is termed dynamic interface (DI). With the growing prominence of uncrewed aerial systems, the USN deems characterizing the DI a crucial step towards employing these systems from air-capable ships. The United States Naval Academy operates a fleet of 108 ft Yard Patrol Craft tasked with training future naval officers. One of these ships has been modified such that the air wake models a DDG to the 1/4 scale. This research documents the DI tests conducted with a remote-piloted drone through mission representative recoveries to the modified Yard Patrol Craft. While operating in the terminal area, the pilot assessed their workload via a modified Cooper Harper scale.

17:00-17:40	ThPo1.3

D2DC: Mid-Air Drone-To-Drone Charging to Enhance Flight Endurance, pp. 893-898

Jaiswal, Archit	University of Florida
Bhunia, Swarup	University of Florida

Last-mile delivery is shipping goods by ground from distribution centers to customers. It is the supply chain's most expensive, complex, and polluting phase. Companies seeking cheaper, faster, and greener logistics are looking to Unmanned Aerial Vehicles (UAVs/drones) for solutions. Several companies aspire to develop Urban Air Mobility (UAM) networks to provide on-demand mobility using an electrical Vertical Takeoff and Landing (eVTOL) aircraft. However, like ground electric vehicles (EVs), UAVs have limited flight endurance due to onboard power constraints. The conventional approach of charging a UAV requires it to halt the flight mission and remain grounded while charging at a slow rate. As a result, UAVs often need detours toward a charging station and add a time penalty on top of the time spent recharging at a station. Such challenges make drone technology less economical and impede its wide-scale adaptation. This paper proposes a novel mid-air Drone-to-Drone (D2D) energy-sharing paradigm, a scalable and cost-effective solution to increase the overall flight endurance of a UAV swarm. This framework allows the UAVs to share charge and sustain each other based on the instructions received from a centralized controller. We introduce innovative components such as multi-level battery architecture, a mid-air energy exchange mechanism, and a cloud-based control unit. We have also developed a drone traffic simulator to evaluate the efficacy of the proposed framework in package delivery tasks. After performing a numerical analysis using the developed simulator, we observed up to 28.24% improvement in the mission success rate and up to 10% increase in the overall flight range of a UAV swarm.

17:00-17:40	ThPo1.4

A Practical Perspective on the Drone-With-A-Slung-Load Problem, pp. 899-904

Aghaee, Fateme	University of Southern Denmark, 6400 Sønderborg, Denmark
Eliker, Karam	Technical University of Denmark
Jouffroy, Jerome	Department of Mechanical and Electrical Engineering, University

Controlling a system consisting of a drone carrying a payload with a cable is a problem of practical importance within UAV control. Contrarily to previous work, this paper investigates a control scheme for this problem where neither the deviation angles of the cable nor the mass of the load is known or measured, with an emphasis on simplicity and applicability on a wide array of available flight controllers. Our approach combines differential-algebraic considerations for motion planning and trajectory generation, together with simple controllers used for feedback. Simulation results are proposed to illustrate the potential of the approach.

17:00-17:40	ThPo1.5

Low-Cost Differential Flatness Identification for Trajectory Planning and Tracking of Small Fixed-Wing UAVs in Dense Environments, pp. 905-910

Liu, Tianqing	National University of Defense Technology
Wang, Mengyun	National University of Defense Technology
Niu, Yifeng	National University of Defense Technology
Li, Jie	National University of Defense Technology
Zhou, Han	National University of Defense Technology

Differential-flatness-based trajectory planning and tracking is a promising approach for small fixed-wing UAVs traversing dense obstacle environments. However, there is a gap between numerical simulations and experiments due to the lack of effective identification methods for differential flatness. In this paper, we develop a practical 3-dimensional differential flatness of fixed-wing UAVs and propose a corresponding identification method. First, a signal-to-thrust model is introduced into differential flatness to directly work with general-purpose flight control units (FCUs) and benefit the identification. Second, a low-cost parameter identification method for differential flatness is proposed without requiring expensive or laborious pre-measurements. Third, the methods to apply them to high-quality trajectory planning and tracking are presented. High-fidelity semi-physical simulations demonstrate that our methods can navigate a small fixed-wing UAV through dense environments, and comparison tests show the superiority of the proposed identification method.

17:00-17:40	ThPo1.6

Towards Probabilistic Clearance, Explanation and Optimization, pp. 911-916

Kohaut, Simon	TU Darmstadt
Flade, Benedict	Honda Research Institute Europe GmbH
Dhami, Devendra Singh	Eindhoven University of Technology
Julian, Eggert	Honda Research Institute EU
Kersting, Kristian	TU Darmstadt

Employing Unmanned Aircraft Systems (UAS) beyond visual line of sight (BVLOS) is an endearing and challenging task. While UAS has the potential to significantly enhance today's logistics and emergency response capabilities, unmanned flying objects above the heads of unprotected pedestrians induce similarly significant safety risks. In this work, we make strides towards improved safety and legal compliance in applying UAS in two ways. First, we demonstrate navigation within the Probabilistic Mission Design (ProMis) framework. To this end, our approach translates Probabilistic Mission Landscapes (PML) into a navigation graph and derives a cost from the probability of complying with all underlying constraints. Second, we introduce the clearance, explanation, and optimization (CEO) cycle on top of ProMis by leveraging the declaratively encoded domain knowledge, legal requirements, and safety assertions to guide the mission design process. Based on inaccurate, crowd-sourced map data and a synthetic scenario, we illustrate the application and utility of our methods in UAS navigation.

ThPo2	MIKIS Foyer
Poster Session II (Poster Session)	
Chair: Tsourveloudis, Nikos	Technical University of Crete

17:50-18:30	ThPo2.2

Pegasus Simulator: An Isaac Sim Framework for Multiple Aerial Vehicles Simulation, pp. 917-922

Jacinto, Marcelo	Instituto Superior Técnico, LARSyS
Pinto, Joao	Instituto Superior Técnico (IST-ID)
Patrikar, Jay	Carnegie Mellon University
Keller, John	Carnegie Mellon University
Cunha, Rita	Instituto Superior Técnico
Scherer, Sebastian	Carnegie Mellon University
Pascoal, Antonio Manuel	Instituto Superior Tecnico

Developing and testing novel control and motion planning algorithms for aerial vehicles can be a challenging task, with the robotics community relying more than ever on 3D simulation technologies to evaluate the performance of new algorithms in a variety of conditions and environments. In this work, we introduce the Pegasus Simulator, a modular framework implemented as an NVIDIA Isaac Sim extension that enables real-time simulation of multiple multirotor vehicles in photo-realistic environments, while providing out-of-the-box integration with the widely adopted PX4-Autopilot and ROS2 through its modular implementation and intuitive graphical user interface. To demonstrate some of its capabilities, a nonlinear controller was implemented and simulation results for two drones performing

aggressive flight maneuvers are presented. Code and documentation for this framework are also provided as supplementary material.

17:50-18:30	ThPo2.3

Image Quality Assessment of UAV Simulator Imagery Based on Different Orthomosaic Maps, pp. 923-928

Toki, Sadikul Alim	Utah State University
Slack, Stockton	Utah State University
Coopmans, Calvin	Utah State University

Drone imagery orthomosaic maps allow for the investigation of landscape features and change over time. However, there are dangers and obstacles associated with drone flight, particularly when testing large-scale drone mapping technologies. New mapping techniques can be tested in simulators without involving actual flights. This research validates different types of maps and compares them with genuine landscape maps to evaluate an orthomosaic simulation platform. Measures of efficiency and accuracy are employed to evaluate the fidelity of the maps produced by the simulator. The capacity of the simulator to imitate various camera payloads can be understood from the spectral signature match between simulated and real maps. Before being deployed to actual drones, this work highlights the value of simulation for quick, low risk testing of advancements in drone sensor technology and mapping algorithms.

17:50-18:30	ThPo2.4

Towards Autonomous Multi-UAV U-Space Operation Planning, pp. 929-934

Grøntved, Kasper Andreas Rømer	University of Southern Denmark
Jepsen, Jes Hundevadt	University of Southern Denmark
Christensen, Anders Lyhne	University of Southern Denmark
Jensen, Kjeld	University of Southern Denmark
Schultz, Ulrik Pagh	University of Southern Denmark
Campusano, Miguel	University of Southern Denmark

One of the main challenges in the real-world adoption of multi-UAV systems lies in the specification of operations and the management of dynamic tasks in varied operational contexts. In this paper, we propose a multi-UAV planning architecture to reduce the level of specialized expertise necessary for handling multi-UAV systems. Furthermore, this work is the first step towards designing a multi-UAV planning architecture that integrates with the U-space services specified in EU regulatory 2021/664. We propose two declarative languages: (i) an Agent-Language for expressing mitigation and safety objectives for individual UAVs, and (ii) an Operation-Language to enable users to plan high-level multi-UAV operations based on the available resources. The languages enable automatic on-the-fly re-planning if any UAVs abort the mission unexpectedly. The initial result of the multi-UAV planning architecture is showcased in three simulated UAVs running as Software-In-The-Loop (SITL), to demonstrate its capabilities.

17:50-18:30	ThPo2.5

An Active Search Strategy with Multiple Unmanned Aerial Systems for Multiple Targets, pp. 935-940

Gao, Chuanxiang	The Chinese University of HongKong
Wang, Xinyi	Chinese University of Hong Kong
Chen, Xi	The Chinese University of Hong Kong
Chen, Ben M.	Chinese University of Hong Kong

The challenge of efficient target searching in vast natural environments has driven the need for advanced multi- UAV active search strategies. This paper introduces a novel method in which global and local information is adeptly merged to avoid issues such as myopia and redundant back-and-forth movements. In addition, a trajectory generation method is used to ensure the search pattern within continuous space. To further optimize multi-agent cooperation, the Voronoi partition technique is employed, ensuring a reduction in repetitive flight patterns and making the control of multiple agents in a decentralized way. Through a series of experiments, the evaluation and comparison results demonstrate the efficiency of our approach in various environments. The primary application of this innovative approach is demonstrated in the search for horseshoe crabs within their wild habitats, showcasing its potential to revolutionize ecological survey and conservation efforts.

17:50-18:30	ThPo2.6

LAIDR4D: Compass-Free Global 4D Pose Tracking of Lighter-Than-Air Indoor Robot Using UWB Ranges, pp. 941-946

Naheem, Khawar	Gwangju Institute of Science and Technology
Kim, Mun Sang	Gwangju Institute of Science and Technology

The autonomous navigation of lighter-than-air indoor robot (LAIDR) demands accurate 4D pose (3D position+1D heading) tracking. Usually, the vision and compass-based sensing systems estimate the 4D pose. However, these sensing systems suffer from indoor light and magnetic field conditions and require the building frame's alignment. This paper proposes an ultra-wideband (UWB) ranging-based compass-free 4D pose tracking of LAIDR named LAIDR4D. The hardware and software of UWB sensors are devised in-house to achieve a compact size, lightweight, and flexible system customization. The low-level firmware is designed using a double-side two-way ranging technique to measure the twin-tag UWB ranges without requiring the clock-synchronization. The high-level localization is developed using a twin extended Kalman filter to deal with the non-linearity of the UWB ranges. Finally, the extensive evaluation shows that the LAIDR4D can reflect root-mean-square-error (RMSE) of under 0.20 m and 3.0° for the 3D positioning and heading, respectively.

Technical Program for Friday June 7

FrA1	MIKIS 1
Swarms II (Regular Session)	
Chair: Leong, Wai Lun	National University of Singapore
Co-Chair: Mejias Alvarez, Luis	Queensland University of Technology

10:30-10:50	FrA1.1

Decentralized Control of UAV Swarms for Bandwidth-Aware Video Surveillance Using NMPC, pp. 947-954

Rezaei Naghadehi, Mohammadamin	Politecnico Di Bari
Manfredi, Gioacchino	Politecnico Di Bari
Racanelli, Vito Andrea	Politecnico Di Bari
De Cicco, Luca	Politecnico Di Bari
Mascolo, Saverio	Politecnico Di Bari

This paper proposes a framework for controlling a drone swarm to achieve two goals: i) covering a desired region of interest through onboard cameras that capture videos to be sent in real-time to a Ground Control Station (GCS), and ii) ensuring the highest video quality possible given the available Internet network bandwidth. Notice that the quality of received videos depends on both the available bandwidth, which directly influences video encoding bitrate, and the altitude of drones, which influences pixel density. Thus, contrary to the conventional assumption of uniform drone altitudes, we let drones track a reference altitude that is function of the time-varying available bandwidth to improve visual quality. To achieve the goals, we propose a leader-follower multi-agent system formation control problem. In this setup, the leader tracks a desired path using Nonlinear Model Predictive Control (NMPC) to cover the area of interest. Follower agents track the leader using NMPC, aiming at maximizing both the total coverage area and the quality of the videos sent to the GCS, considering the constraints imposed by the network available bandwidth. At the same time, we formulate the NMPC problem to ensure that the swarm maintains a formation characterized by a given overlap percentage between the videos captured by the drones while avoiding collisions. This allows dynamical stitching of the received videos at the GCS, enabling the execution of computer vision algorithms for tasks such as object detection and surveillance.

10:50-11:10	FrA1.2

Decentralized Connectivity Maintenance for Multi-Agent Systems Using Control Barrier Functions, pp. 955-962

Bhatia, Pranjal	IIIT Delhi
Basu Roy, Sayan	Indraprastha Institute of Information Technology, Delhi (IIITD)
Baliyarasimhuni, Sujit, P	IISER Bhopal
Mejias Alvarez, Luis	Queensland University of Technology
Mcfadyen, Aaron	Queensland University of Technology

This paper proposes a decentralized control barrier function (CBF) as a solution for distributed global connectivity maintenance for a multi-agent system (MAS). Using a combination of Fiedler value estimation (the second smallest eigenvalue of the Laplacian) and control barrier functions, the proposed method can ensure that agents will remain globally connected in a distributed fashion. The major advantage of using CBF is that it allows us to consider multiple objectives and constraints at the same time. Moreover, it enables the agent connectivity to be increased to a desired level. Mathematical analysis and simulation results demonstrate the efficacy of the approach.

11:10-11:30	FrA1.3

Multi-UAV Distributed Control for Reconfigurable Formations, pp. 963-970

Skantzikas, Kostas	Grenoble INP
Briñón Arranz, Lara	GIPSA-Lab
Susbielle, Pierre	Grenoble-INP UGA GIPSA-Lab
Marchand, Nicolas	GIPSA-Lab CNRS

This paper deals with cooperative formation control design for multi-UAVs. A new control strategy is developed to steer a group of robots to three kinds of evenly spaced formations: circular, linear and circular sector. Our distributed approach enables real-time formation reconfiguration when the parameters of the formations change or when a robot leaves the formation. Communication among robots is used to maintain the robots equally spaced in the desired formation and to avoid collisions during the reconfigurations. Real world experiments with four mini aerial vehicles demonstrate the efficacy of the proposed formation control strategy.

11:30-11:50	FrA1.4

A Highly Scalable, Robust and Decentralized Approach for Multi-UAV Persistent Surveillance, pp. 971-977

Cao, Jiawei	National University of Singapore
Leong, Wai Lun	National University of Singapore
Teo, Rodney	National University of Singapore

Multi-robot patrolling is known to be challenging, especially in a decentralized manner. The state-of-the-art decentralized approaches are either suboptimal or usually require exchange of information that would potentially limit their scalability. This paper presents a novel decentralized approach of high scalability and robustness to multi-UAV persistent surveillance. Our solution decentralizes a cyclic strategy while considering communication constraints. We give a theoretical derivation of the decentralized algorithm with convergence analysis. In addition, we consider practical issues such as motion constraints and potential livelocks in our implementation. The proposed

approach is extensively tested and analyzed in a medium-fidelity swarm simulator to minimize the gap between simulation and real experiments.

11:50-12:10	FrA1.5

Multi-Agent Reinforcement Learning Based Drone Guidance for N-View Triangulation, pp. 978-985

Gavin, Timothée	Thales LAS
Lacroix, Simon	LAAS/CNRS
Bronz, Murat	ENAC

This article presents a novel approach for controlling a swarm of drones that can track the location of a flying target using onboard omnidirectional cameras. The drones use Multi-Agent Reinforcement Learning (MARL) to learn decentralized policies that optimize their formation and motion around the target, minimizing the uncertainty in the triangulated position. We design a reward function that encourages the trackers to minimize the trace of the covariance matrix of the triangulated position, which is derived from an analytical model of uncertainty propagation. We use Multi-Agent PPO (MAPPO), an extension of Proximal Policy Optimization (PPO) to the multi-agent setting, to train the policies using this common reward function that encourages good formation and avoids collisions. We validate our approach in simulation and real-flight experiments, demonstrating its effectiveness and potential in enhancing autonomous multi-drone coordination for precise tracking.

12:10-12:30	FrA1.6

Trajectory Tracking with Obstacle Avoidance for Autonomous UAV Swarms Based on Distributed Model Predictive Control, pp. 986-993

Vavelidou, Despoina	University of West Attica
Protoulis, Teo	University of West Attica
Alexandridis, Alex	University of West Attica

Multi-agent quadcopter systems, a specialized class of unmanned aerial vehicles (UAVs), have become key players in various industries, showing potential for further growth. However, the inherently nonlinear and complex behavior of quadcopters, coupled with the need for collision and obstacle avoidance within the swarm, while simultaneously achieving collective goals, poses significant challenges for efficient control. Trajectory tracking - a particularly demanding task for swarms - requires a delicate balance between precise tracking and safe navigation. In this work, we address the challenge of trajectory tracking for multi-agent quadcopter configurations through a novel distributed model predictive control (DMPC) framework, with individual local controllers for each agent. For a balanced control scheme, we employ both PID controllers for angle regulation and linear adaptive MPC (LAMPC) controllers for three-dimensional position control. The local MPC schemes ensure safe trajectory tracking, without the need to use predetermined reference trajectories for each agent and predefined formation strategies. Simulation results of the proposed framework demonstrate advanced robustness and dynamic adaptation to unpredicted situations.

FrA2	**MIKIS 2**
UAS Communications (Regular Session)	
Chair: Ellinas, Georgios	University of Cyprus
Co-Chair: Coopmans, Calvin	Utah State University

10:30-10:50	FrA2.1

SUAS Command-And-Redundant-Control Communications System with ROS 2 Data Bridge for Aerial Remote Sensing Rapid Development, pp. 994-1001

Coopmans, Calvin	Utah State University
Snider, Richard M.	Utah State University
Slack, Stockton	Utah State University
Beckwith, A. J.	Utah State University

As small, uncrewed systems (sUAS) grow in popularity and in number, larger and larger drone aircraft will become more common--up to the FAA limit of 55-pound gross take-off weight (GTOW) and beyond. Due to their larger payload capabilities, longer flight time, and better safety systems, autonomous systems that maximize CFR 14 Part 107 flight drone operations regulations will become more common, especially for operations such as imagery or other data collection which scale well with longer flight times and larger flight areas. In this new paper, a unique all-electric 55-pound VTOL transition fixed-wing sUAS specifically engineered for scientific data collection named ``GreatBlue'' is presented, along with systems, communications, scientific payload, data collection and processing, package delivery payload, ground control station, and mission simulation system. Able to fly for up to 2.5 hours while collecting multispectral remotely sensed imagery, the unique GreatBlue system is shown, along with a package delivery flight example, flight data from two scientific data collection flights over California almond fields and a Utah Reservoir are shown including flight plan vs. as-flown.

10:50-11:10	FrA2.2

Real-Time Mapping for Teleoperation Systems in VR of Unmanned Aerial Vehicles, pp. 1002-1009

Ramírez, Germán	Centro De Investigaciones En Óptica
Verdìn, Rodolfo Isaac	Centro De Investigaciones En Óptica
Flores, Gerardo	Centro De Investigaciones En Óptica

This study presents the development of virtual environments as control centers for remote teleoperation tasks of unmanned aerial vehicles (UAVs). Initially, our focus lies on reconstructing outdoor environments using a ZED mini stereo camera and reconstructing them through point cloud techniques. The virtual environment is hosted in UNITY, a widely recognized platform for designing virtual reality (VR) video games. Within this environment, a digital twin UAV is embedded, tasked with replicating the real positions and

orientations of the vehicle. To achieve this, we propose using PID and PD control for the positions and rotations of the virtual vehicle, allowing it to follow the desired position, in this case, the real position of the vehicle. A series of experiments were conducted in outdoor and indoor environments to validate the functionality of this approach.

11:10-11:30	FrA2.3

Human Factors Issues of Limited Connectivity in Advanced UAS Operations: Insights and Prospects, pp. 1010-1017

Karvonen, Hannu	VTT Technical Research Centre of Finland
Kramar, Vadim	VTT Technical Research Centre of Finland
Anttonen, Antti	VTT
Höyhtyä, Marko	VTT Technical Research Centre of Finland Ltd
Järvenpää, Mika	Nokia Solutions and Networks Oy

This paper presents an assessment of relevant human factors issues of advanced unmanned aircraft systems (UAS), which are affected by limited data connectivity. Based on an earlier literature review, we categorize these issues under three aspects, namely system design, human factors evaluation, and operation process. Under each aspect, we examine in detail the pertinent human factors engineering insights regarding unmanned aircraft systems and their connectivity. We also present prospects for future research by listing relevant human factors-related research questions for each aspect regarding limited connectivity in UAS operations. A key conclusion of the paper is that similar human factors issues, such as automation awareness and trust, apply for advanced UAS operations as they do to other well-studied automated safety-critical environments.

11:30-11:50	FrA2.4

Dynamic Deployment and Control of an NDN Network for Military Multi-UAVs Based Surveillance Applications, pp. 1018-1025

A. R. da Cruz, Otávio	Federal University of Rio Grande Do Sul
Pereira, Carlos Eduardo	Federal University of Rio Grande Do Sul
Silva, Antonio Arlis Santos da	Federal University of Rio Grande Do Sul
Javidi da Costa, João Paulo	Hochschule Hamm-Lippstadt - HSHL
Milheiro Mendes, Paulo Jorge	Airbus
Pignaton de Freitas, Edison	Federal University of Rio Grande Do Sul

The military usage of Unmanned Aerial Vehicles (UAVs) has garnered attention, especially after their employment in the Ukrainian war. Despite the most commented lethal usage, they have many other applications from which surveillance for imagery acquisition is one of primal importance. Using a stand-alone UAV for this purpose is well-known, but to cope with the scale of battlefield operations, using multi-UAV systems is an asset of great value. However, these systems rely on ad hoc networks that require solutions beyond conventional ones based on the Internet Protocol (IP). This paper addresses this concern by proposing a communication support mechanism for multi-UAV military surveillance systems based on the Information-Centric Networks (ICN) paradigm. The proposed approach consists of the dynamic deployment of an ICN network based on microservices architecture, where the communication services of each UAV are deployed according to their resources. The solution is validated in a simulated battlefield scenario where a surveillance UAV provides data demanded by other nodes. The results demonstrate that the proposed solution minimizes the data delivery delays by successfully deploying the customized set of microservices to support the transmission, even when a UAV with a low battery level is replaced at runtime.

11:50-12:10	FrA2.5

Coordinating Cooperative Perception in Urban Air Mobility for Enhanced Environmental Awareness, pp. 1026-1033

Häckel, Timo	Hamburg University of Applied Sciences
von Roenn, Luca	Helmut Schmidt University Hamburg
Juchmann, Nemo	Hamburg University of Applied Sciences
Fay, Alexander	Helmut-Schmidt-Universität
Akkermans, Rinie	Hamburg University of Applied Sciences
Tiedemann, Tim	Hamburg University of Applied Sciences
Schmidt, Thomas C.	Hamburg University of Applied Sciences

The trend for Urban Air Mobility (UAM) is growing with prospective air taxis, parcel deliverers, and medical and industrial services. Safe and efficient UAM operation relies on timely communication and reliable data exchange. In this paper, we explore Cooperative Perception (CP) for Unmanned Aircraft Systems (UAS), considering the unique communication needs involving high dynamics and many UAS. We propose a hybrid approach combining local broadcast with a central CP service, inspired by centrally managed U-space and broadcast mechanisms from automotive and aviation domains. In a simulation study, we show that our approach significantly enhances the environmental awareness for UAS compared to fully distributed approaches, with an increased communication channel load, which we also evaluate. These findings prompt a discussion on communication strategies for CP in UAM and the potential of a centralized CP service in future research.

12:10-12:30	FrA2.6

Performance Evaluation of a Prototype UAV-Based Secure Communication System Employing ROS and Chaotic Communications, pp. 1034-1041

Souli, N.	University of Cyprus
Stavrinides, Stavros	International Hellenic University
Kardaras, Panagiotis	University of Cyprus
Picos, Rodrigo	University of Cyprus

Karatzia, Maria — KIOS CoE and University of Cyprus
Kolios, Panayiotis — University of Cyprus
Ellinas, Georgios — University of Cyprus

Providing secure communications has become imperative in single- and multi-agent systems that need to ensure the integrity, confidentiality, and availability of the transmitted data, especially when these systems are employed in critical infrastructure applications. This work presents a novel approach for secure communications between a group of unmanned aerial vehicles (UAVs) to safeguard the confidentiality of the data exchanged in such a multi-agent system, employing the robot operating system (ROS), a virtual private network (VPN), and a chaotic based communication architecture. Specifically, a custom ROS-based framework is developed to collect and distribute the UAV sensor data, while a VPN network is deployed as the first layer of security for the system. Subsequently, a lightweight chaotic-based module is incorporated as the second layer of security to enable secure communications between the UAVs in real time. To evaluate the proposed system, a prototype multi-UAV system is designed, implemented, and extensively tested in a real-world environment. The proposed system achieves secure real-time communications, with low power consumption and minimal processing resources (CPU and RAM usage), demonstrating its applicability for the energy-constrained UAV-based system under consideration.

FrA3	**KAM**
Perception and Cognition (Regular Session)	
Chair: Alkendi, Yusra	Technology Innovation Institute
Co-Chair: Karampinis, Vasileios	National Technical University of Athens (NTUA)

10:30-10:50 — FrA3.1

LiDAR Stereo Visual Inertial Pose Estimation Based on Feedforward and Feedbacks, pp. 1042-1049

Yang, Wenyu — The Hong Kong Polytechnic University
Hu, Haochen — The Hong Kong Polytechnic University
Tse, Kwai-Wa — The Hong Kong Polytechnic University
Chen, Shengyang — The Hong Kong Polytechnic University
Wen, Weisong — The Department of Aeronautical and Aviation Engineering, the Hon
Wen, Chih-Yung — The Hong Kong Polytechnic University

In this paper, we present a LiDAR-visual-inertial Odometry (LVIO) based on feedforward and feedback. Compared to traditional Kalman filter-based methods or optimization-based methods for sensor fusion, the proposed system achieves sensor fusion through feedforward and feedback. This system, named Feedforward-feedback LiDAR Visual Inertial System (FLiVIS) consists of a Visual-Inertial Odometry (VIO) subsystem and a LiDAR-Inertial Odometry (LIO) subsystem, these two subsystems are coupled through complementary filters. Instead of directly integrating gyroscope data and accelerometer data, our framework leverages the complementary nature of gyroscope and accelerometer measurements. FLiVIS is evaluated on public datasets, it achieves a relative translation error of 0.68% on the KITTI dataset and 0.138 m absolute translation error on the NTU-Viral dataset, respectively. The experiment results demonstrate the accuracy and robustness of FLiVIS with respect to other state-of-the-art counterparts. FLiVIS is capable of accommodating both multi-line spinning LiDARs and emerging solid-state LiDARs, which employ distinct scanning patterns. Additionally, it can perform real-time operations on a range of platforms, from laptops to upboard processors.

10:50-11:10 — FrA3.2

FlyNeRF: NeRF-Based Aerial Mapping for High-Quality 3D Scene Reconstruction, pp. 1050-1055

Dronova, Maria — Skolkovo Institute of Science and Technology
Cheremnykh, Vladislav — Skolkovo Institute of Science and Technology
Kotcov, Alexey — Skolkovo Institute of Science and Technology
Fedoseev, Aleksey — Skolkovo Institute of Science and Technology
Tsetserukou, Dzmitry — Skolkovo Institute of Science and Technology

Current methods for 3D reconstruction and environmental mapping frequently face challenges in achieving high precision, highlighting the need for practical and effective solutions. In response to this issue, our study introduces FlyNeRF, a system integrating Neural Radiance Fields (NeRF) with drone-based data acquisition for high-quality 3D reconstruction. Utilizing unmanned aerial vehicles (UAV) for capturing images and corresponding spatial coordinates, the obtained data is subsequently used for the initial NeRF-based 3D reconstruction of the environment. Further evaluation of the reconstruction render quality is accomplished by the image evaluation neural network developed within the scope of our system. Depending on the results of the image evaluation module, our algorithm determines the position for additional image capture, thereby improving the reconstruction quality.

The neural network introduced for render quality assessment demonstrates an accuracy of 97%. Furthermore, our adaptive methodology enhances the overall reconstruction quality, resulting in an average improvement of 2.5 dB in Peak Signal-to-Noise Ratio (PSNR) for the 10{%} quantiles. The FlyNeRF demonstrates promising results, offering advancements in such fields as environmental monitoring, surveillance, and reconstruction of digital twins, where high-fidelity 3D reconstructions are crucial.

11:10-11:30 — FrA3.3

Dynamic-Obstacle Relative Localization Using Motion Segmentation with Event Cameras, pp. 1056-1063

Alkendi, Yusra — Technology Innovation Institute
Abdulhay, Oussama — Khalifa University of Science and Technology
Ahmed Humais, Muhammad — Khalifa University of Science and Technology
Azzam, Rana — Khalifa University of Science and Technology
Seneviratne, Lakmal — Khalifa University of Science and Technology

Zweiri, Yahya Khalifa University

The ability to detect and localize dynamic obstacles within a robot's surroundings while navigating low-light environments is crucial for ensuring robot safety and the continuity of its mission. Event cameras excel in capturing motion within scenes clearly without motion blur, due to their asynchronous nature. These sensors are distinguished by their ability to trigger events with microsecond temporal resolution, possess a high dynamic range, and achieve low latency. In this work, we introduce a framework for a drone equipped with an event camera, named E-DoRL. This framework is specifically designed to address the challenge of detecting and localizing dynamic obstacles that are not previously known, ensuring safe navigation. E-DoRL processes raw event streams to estimate the relative position between a moving robot and dynamic obstacles. It employs a Graph Transformer Neural Network (GTNN) to extract spatiotemporal correlations from event streams, identifying active event pixels of moving objects without prior knowledge of scene topology or camera motion. Based on these identifications, E-DoRL is designed to determine the relative position of moving obstacles with respect to a dynamic unmanned aerial vehicle (UAV). E-DoRL outperformed state-of-the-art frame-based object tracking algorithms in good light scenarios (100 lux), by achieving 59.7% and 25.9% reduction in the mean absolute error (MAE) associated with the X and Y estimates, respectively. Additionally, when tested under much lower light illuminance (0.8 lux), E-DoRL consistently maintained its performance without any degradation, as opposed to image-based techniques that are highly sensitive to lighting conditions.

11:30-11:50 FrA3.4

Autonomous UAV Volcanic Plume Sampling Based on Machine Vision and Path Planning, pp. 1064-1071

Rolland, Edouard George Alain — University of Southern Denmark
Grøntved, Kasper Andreas Rømer — University of Southern Denmark
Christensen, Anders Lyhne — University of Southern Denmark
Watson, Iain Matthew — University of Bristol
Richardson, Thomas — University of Bristol

Drones currently serve as a valuable tool for in-situ sampling of volcanic plumes, but they still involve manual piloting. In this paper, we enable autonomous dual plume sampling by using a machine vision model to detect eruptions. When an eruption is detected, a sampling trajectory is automatically generated to intercept the plume twice to collect comparative samples. The machine vision model is developed by training a YOLOv8 object detection model thanks to a database of 1505 images that feature labelled plumes. The obtained average precision value of the model's plume class, at 90.7%, is comparable to that of state-of-the-art models for wildfire smoke monitoring. The performance of this method is assessed using a software-in-the-loop simulation of the drone and a simulated plume model. Although the results confirm the efficacy of using a machine vision model for triggering an onboard path-planning algorithm, it also suggests the potential for a hybrid strategy that integrates visual servoing with our proposed path-planning approach.

11:50-12:10 FrA3.5

Ensuring UAV Safety: A Vision-Only and Real-Time Framework for Collision Avoidance through Object Detection, Tracking, and Distance Estimation, pp. 1072-1079

Karampinis, Vasileios — National Technical University of Athens (NTUA)
Arsenos, Anastasios — National Technical University of Athens
Filippopoulos, Orfeas — Hellenic Drones S.A
Petrongonas, Evangelos — National Technical University of Athens
Skliros, Christos — Hellenic Drones S.A
Kollias, Dimitrios — Queen Mary University of London
Kollias, Stefanos — National Technical University of Athens
Voulodimos, Athanasios — National Technical University of Athens

In the last twenty years, unmanned aerial vehicles (UAVs) have garnered growing interest due to their expanding applications in both military and civilian domains. Detecting non-cooperative aerial vehicles with efficiency and estimating collisions accurately are pivotal for achieving fully autonomous aircraft and facilitating Advanced Air Mobility (AAM). This paper presents a deep-learning framework that utilizes optical sensors for the detection, tracking, and distance estimation of non-cooperative aerial vehicles. In implementing this comprehensive sensing framework, the availability of depth information is essential for enabling autonomous aerial vehicles to perceive and navigate around obstacles. In this work, we propose a method for estimating the distance information of a detected aerial object in real- time using only the input of a monocular camera. To train our deep learning components for the object detection, tracking and depth estimation tasks we utilize the Amazon Airborne Object Tracking (AOT) Dataset. In contrast to previous approaches that integrate the depth estimation module into the object detector, our method formulates the problem as image-to-image translation. We employ a separate lightweight encoder-decoder network for efficient and robust depth estimation. In a nutshell, the object detection module identifies and localizes obstacles, conveying this information to both the tracking module for monitoring obstacle movement and the depth estimation module for calculating distances. Our approach is evaluated on the Airborne Object Tracking (AOT) dataset which is the largest (to the best of our knowledge) air-to-air airborne object dataset.

12:10-12:30 FrA3.6

Vision-Only Pose and Relative Distance Estimation for Leading Quadrotor UAV from Following UAV, pp. 1080-1084

Xu, Xiangpeng — Sun Yat-Sen University
Chujun, Li — Sun Yat-Sen University
Zhuge, Sheng — Sun Yat-Sen University
Yang, Xia — Sun Yat-Sen University
Khoo, Boo Cheong — National University of Singapore
Srigrarom, Sutthiphong — National University of Singapore
Chan, Wee Kiat — National University of Singapore
Leong, Wai Lun — National University of Singapore

Lin, Bin	Fujian Normal University
Zhang, Xiaohu	Sun Yat-Sen University

Multi-rotor unmanned aerial vehicle (UAV) systems have been applied in many scenarios to improve the flexibility and effectiveness of specific tasks. Common tasks include pursuing, intercepting, and training. To increase efficiency and independent operation, particularly by reducing reliance on wireless communication and enhancing stability during cooperative control of systems, this paper introduces a vision-only and universal method for pose estimation and relative distance calculation. Firstly, key components of a UAV are detected through a two-step method. A novel feature encoding method is presented to establish the 2D-3D correspondence with the known 3D structure of UAVs and solve the Perspective-n-Point (PnP) problem. To mitigate misdetections in air-to-air scenarios, a robust auto-weighting Levenberg-Marquardt (AWLM) algorithm was integrated into pose estimation process. Secondly, with the detection of UAVs key points, the UAV pose and relative distance from the observer can be estimated through geometry. Flight experiments of a two-UAV leader-follower system in GPS-denied environments have been conducted to verify the efficacy of the proposed approach. The results show that the calculation error is less than 5%, i.e. less than a meter at relative distances of up to 20 meters, achieved at a processing speed of 30 milliseconds per frame. This signifies the highest precision and fastest processing speed among several similar methods. Keywords: Leader-follower UAV Systems, Multi-rotors UAVs, Motion Perception, Robotics Machine Vision, 6D Pose Estimation.

FrA4	**DILOVO**
Navigation (Regular Session)	
Chair: Sarcinelli-Filho, Mário	Federal University of Espirito Santo
Co-Chair: Lee, Kyuman	Kyungpook National University

10:30-10:50	FrA4.1

Active Heading Planning for Improving Visual-Inertial Odometry, pp. 1085-1092

Lee, Joohyuk	Kyungpook National University
Lee, Kyuman	Kyungpook National University

Visual-inertial odometry (VIO) is a technique to estimate the motion of a vehicle platform by fusing camera and inertial sensor data. It operates effectively in GPS-denied environments such as indoors and is widely utilized in applications like autonomous navigation of unmanned aerial vehicles (UAVs) due to its real-time performance and high localization accuracy. However, since VIO relies on textures in the environment or features extracted from image frames, localization may easily fail if the number of feature points in the image is insufficient, or the UAV faces a low-texture environment. To address these issues, we propose an active VIO algorithm by planning heading angles autonomously. This algorithm improves VIO accuracy and maintains robust localization even in an unknown environment by employing heading planning to acquire more feature points in the subsequent image frames. To achieve this, we first divide an image frame into several sections and count the number of feature points in each section. Next, we determine the desired heading angle based on the feature-occupied ratio of each section. The proposed approach is validated in various cases in a simulation environment that mimics an indoor warehouse.

10:50-11:10	FrA4.2

Riding the Rollercoaster: Improving UAV Piloting Skills with Augmented Visualization and Collaborative Planning, pp. 1093-1100

Franceschini, Riccardo	Eurecat, Centre Tecnològic De Catalunya, 08290 Cerdanyola Del Va
Javier, Rodriguez	Eurecat
Fumagalli, Matteo	Danish Technical University
Cayero, Julian Cayero	Eurecat

Operating unmanned aerial vehicles (UAVs) in complex environments can be challenging, particularly for inexperienced operators. This paper introduces a method aimed at enhancing the piloting experience by incorporating an intermediary processing layer between the remote controller and the drone. The presented approach empowers operators to control both the speed and direction of the UAV along a secure path, which is continuously computed and overlaid onto the operator's camera stream. The UAV autonomously plans and executes this path, adapting to the operator's commands and environmental changes. The primary aim of this proposed solution is to enhance the operator's situational awareness, perception, as well as the safety and efficiency of UAV navigation. The paper outlines the system and methodology employed, showing its ability to operate at a high enough frequency to enable seamless user interactions. Furthermore, to validate the effectiveness of this approach, a real-world test and a user-based experimental study conducted in a simulation environment with an audience comprising varying levels of pilot expertise have been carried out.

11:10-11:30	FrA4.3

Local Gaussian Modifiers (LGMs): UAV Dynamic Trajectory Generation for Onboard Computation, pp. 1101-1108

Fernandez-Cortizas, Miguel	Universidad Politecnica De Madrid
Perez-Saura, David	UPM
Perez-Segui, Rafael	Universidad Politécnica De Madrid
Rodriguez-Vazquez, Javier	Universidad Politécnica De Madrid
Cely, Juan S.	Rey Juan Carlos University
Campoy, Pascual	Universidad Politecnica Madrid

Agile autonomous drones are becoming increasingly popular in research due to the challenges they represent in fields like control, state estimation, or perception at high speeds. When all algorithms are computed onboard the UAV, computational limitations make the task of agile flight even more difficult.

One of the most computationally expensive tasks in agile flight is the generation of optimal trajectories. When these trajectories must be updated online due to changes in the environment or uncertainties, this high computational cost may result in insufficient time to reach the desired waypoints, which could cause a drone crash in cluttered environments.

In this paper, we present Local Gaussian Modifiers (LGMs), a fast and lightweight way of modifying computationally heavy trajectories when recalculating them in time is not possible due to computational limitations. Moreover, we propose a strategy for deciding when is convenient to use these modifiers or recalculate the whole trajectory based on an estimation of the computational time of this trajectory generation. A trajectory blending procedure is also proposed to ensure smoothness in UAV control when a new trajectory is computed.

Our approach was validated in simulation, being able to pass through a race circuit with moving gates, achieving speeds up to 16.0 m/s. Real flight validation was also performed achieving speeds up to 4.0 m/s in a fully autonomous pipeline using onboard computing.

11:30-11:50	FrA4.4

UAV-Assisted Visual SLAM Generating Reconstructed 3D Scene Graphs in GPS-Denied Environments, pp. 1109-1116

Radwan, Ahmed	University of Luxembourg
Tourani, Ali	University of Luxembourg
Bavle, Hriday	PhD Student at Universidad Politecnica De Madrid
Voos, Holger	University of Luxembourg
Sanchez-Lopez, Jose-Luis	SnT, University of Luxembourg

Aerial robots play a vital role in various applications where the situational awareness of the robots concerning the environment is a fundamental demand. As one such use case, drones in GPS-denied environments require equipping with different sensors (e.g., vision sensors) that provide reliable sensing results while performing pose estimation and localization. In this paper, reconstructing the maps of indoor environments alongside generating 3D scene graphs for a high-level representation using a camera mounted on a drone is targeted. Accordingly, an aerial robot equipped with a companion computer and an RGB-D camera was built and employed to be appropriately integrated with a Visual Simultaneous Localization and Mapping (VSLAM) framework proposed by the authors. To enhance the situational awareness of the robot while reconstructing maps, various structural elements, including doors and walls, were labeled with printed fiducial markers, and a dictionary of the topological relations among them was fed to the system. The VSLAM system detects markers and reconstructs the map of the indoor areas, enriched with higher-level semantic entities, including corridors and rooms. Another achievement is generating multi-layered vision-based situational graphs containing enhanced hierarchical representations of the indoor environment. In this regard, integrating VSLAM into the employed drone is the primary target of this paper to provide an end-to-end robot application for GPS-denied environments. To show the practicality of the system, various real-world condition experiments have been conducted in indoor scenarios with dissimilar structural layouts. Evaluations show the proposed drone application can perform adequately w.r.t. the ground-truth data and its baseline.

11:50-12:10	FrA4.5

Elevation Angle Redundancy from Barometric Altitude in Multipath-Affected Phased Array Radio Navigation of UAVs, pp. 1117-1124

Okuhara, Mika	Norwegian University of Science and Technology
Bryne, Torleiv Håland	Norwegian University of Science and Technology
Gryte, Kristoffer	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

Phased Array Radio Systems (PARS) are a promising alternative or backup to Global Navigation Satellite Systems (GNSS) based positioning, offering higher signal-to-noise ratio (SNR), narrow beam communication and robust encryption to mitigate these risks. However, PARS systems face multipath challenges, particularly when radio signals are reflected off horizontal surfaces such as flat fields, lakes, and oceans, affecting the accuracy of elevation angle measurements.

The proposed solution introduces the concept of a recalculated elevation angle, inspired by grazing angle determination, as an alternative to the potentially uncertain elevation angle provided by PARS. Derived from PARS range measurements, barometric altitude, and the effective Earth radius, the recalculated elevation angle aims to overcome the limitations of previous methods that failed to fully consider the Earth's curvature, leading to inaccuracies in elevation angle estimates. Our approach uniquely incorporates the recalculated elevation angle into the PARS-aided inertial navigation system (INS), enhancing positioning accuracy, especially when the UAV is operating near the ground antenna.

The paper evaluates the performance of the navigation system using the recalculated elevation angle using field test data. The root mean square vertical position error was improved by a factor of 7.5 with the proposed method compared to using multipath affected elevation measurement. The results show that the recalculated elevation angle is a viable alternative to the multipath affected measured elevation angle in PARS-based navigation.

12:10-12:30	FrA4.6

Localization of Unmanned Aircraft Systems Using Bio-Inspired Algorithms: An Experimental Study, pp. 1125-1131

Araujo-Neto, Wolmar	Universidade Federal Do Espírito Santo
Villa, Daniel Khede Dourado	Federal University of Espírito Santo
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

This article describes the integrated application of the bio-inspired optimization algorithm LBBA and Digital Compass to enhance the localization of drones in autonomous missions. The work presents a approach covering Airworthiness, Localization and Sensor Fusion.

The LBBA algorithm, using data from a LIDAR sensor and information from a Digital Compass, shows significant advances in the safety and effectiveness of autonomous operations on mobile bases. Now, the proposal is to use this advantage to assist in locating drones on a known map.

This study contributes to the continuous evolution of autonomous drone technology, promoting a more effective and secure integration of these systems in laboratory testing environments. The results suggest that the combination of 2D localization from a ground robot with interaction with an aerial one offers a robust and reliable solution for the precise localization of drones, paving the way for future innovations in the field of unmanned aerial vehicles.

FrB1	**MIKIS 1**
Aerial Robotics in Inspection and Maintenance Operations I (Invited Session)	
Chair: Ruggiero, Fabio	Università Degli Studi Di Napoli "Federico II"
Co-Chair: Zoric, Filip	University of Zagreb, Faculty of Electrical Engineering and Computing
Organizer: Gabellieri, Chiara	University of Twente
Organizer: Silano, Giuseppe	Czech Technical University in Prague
Organizer: Selvaggio, Mario	University of Naples Federico II

14:00-14:20	FrB1.1

Shared-Control Teleoperation Methods for a Cable-Suspended Dual-Arm Unmanned Aerial Manipulator (I), pp. 1132-1139

Selvaggio, Mario	University of Naples Federico II
Esposito, Federico	University of Naples Federico II
Lippiello, Vincenzo	Universita' Di Napoli Federico II
Ruggiero, Fabio	Università Degli Studi Di Napoli "Federico II"

This paper introduces two shared-control teleoperation methods for remotely executing long-reach tasks with a cable-suspended dual-arm unmanned aerial manipulator. The proposed techniques aim to improve task performance and user experience during remote tasks involving interaction with the environment. Two application scenarios are envisioned: pushing against a flat surface to emulate in-contact inspection tasks of infrastructures, and object grasping to simulate debris removal in cluttered environments. The effectiveness of the two shared-control teleoperation methods is evaluated through a human-subjects study involving 10 participants commanding the simulated robot via a joystick interface. Statistical analysis demonstrates significant enhancements in task performance and system usability when using the proposed methods compared to standard teleoperation.

14:20-14:40	FrB1.2

A Model-Based Oscillation Suppression Approach for a Cable-Suspended Dual-Arm Aerial Manipulator (I), pp. 1140-1147

D'Ago, Giancarlo	European Organization for Nuclear Research (CERN), University Of
Selvaggio, Mario	University of Naples Federico II
Marzio, Chiara	University of Naples Federico II
Buonocore, Luca Rosario	CERN
Suarez, Alejandro	University of Seville
Gonzalez-Morgado, Antonio	Universidad De Sevilla
Villanueva, Jose	Escuela Técnica Superior De Ingeniería, Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla - Q-4118001-I
Ruggiero, Fabio	Università Degli Studi Di Napoli "Federico II"

In aerial manipulators, the presence of cables between the aerial platform and the articulated system is beneficial to increase the distance between rotors' blades and the obstacles in the workspace and absorb unavoidable impacts arising during the interaction with the environment. However, cables also produce pendulum-like oscillatory behaviour due to dynamic coupling and to the effect of external forces when the robot navigates in free space through the environment. This paper presents a model-based control approach for the suppression of oscillations in cable-suspended dual-arm aerial manipulators. Contrary to many oscillation suppression techniques that act on the suspension platform, we exploit the dynamics of the articulated system to achieve the same scope. A linear controller is devised applying a partial feedback linearization technique for the unactuated variables of our system, i.e. the cables. Simulation and experimental tests are carried out using a quadrotor equipped with a cable-suspended dual-arm system to validate our proposed framework. With our control technique drone-induced oscillations were reduced by up to 89%, with a settling time of 2.5 seconds.

14:40-15:00	FrB1.3

Autonomous Visual Inspection of Industrial Plants Using Unmanned Aerial Vehicles (I), pp. 1148-1154

Scognamiglio, Vincenzo	University of Naples "Federico II"
Caccavale, Riccardo	Università Degli Studi Di Napoli Federico II
Merone, Pasquale	University of Naples Federico II
De Crescenzo, Alessandro	Neabotics Srl
Ruggiero, Fabio	Università Degli Studi Di Napoli "Federico II"
Lippiello, Vincenzo	Universita' Di Napoli Federico II

The development of autonomous systems has spurred numerous innovative inspection strategies. Some operations, such as monitoring the condition of industrial structures, typically entail significant deployment of human resources and pose risks to human safety. In this context, this paper presents a visual inspection framework that leverages unmanned aerial vehicles to explore designated facilities, identifying structural damages such as cracks or fissures for inspection. The proposed approach integrates autonomous navigation and high-level decision-making capabilities to effectively explore predefined points of interest within partially known environments and to select and inspect candidate spots for further analysis. The framework is validated through both simulated and real-world experiments conducted in GPS-denied environments, utilizing only onboard UAV capabilities.

15:00-15:20	FrB1.4

Efficient Development of Model-Based Controllers in PX4 Firmware: A Template-Based Customization Approach (I), pp. 1155-1162

D'Angelo, Simone	Università Degli Studi Di Napoli Federico II
Pagano, Francesca	Università Degli Studi Di Napoli Federico II
Longobardi, Francesco	Università Federico II Di Napoli
Ruggiero, Fabio	Università Degli Studi Di Napoli "Federico II"
Lippiello, Vincenzo	Universita' Di Napoli Federico II

This paper introduces a refined iteration of the PX4 autopilot firmware tailored to support developers in integrating bespoke control algorithms alongside the existing control framework. The proposed methodology employs a template-driven approach and introduces two novel control modules, thereby enabling users to harness all firmware functionalities within their custom modalities, including the QGroundControl interface, while retaining all the standard modules and compatibility with the QGroundControl interface. With its transparent and adaptable structure, the software framework presented herein lays a robust groundwork for implementing tailored and specialized solutions across diverse aerospace domains. As a practical demonstration, we apply the developed firmware to the domain of inspection and maintenance, wherein it incorporates an admittance controller and a model-based control algorithm for a tiltable drone equipped with a sensorized tool. The efficacy and versatility of the proposed approach are validated through simulations and empirical trials conducted across multiple aerial platforms. The produced code is released to the community.

15:20-15:40	FrB1.5

An Experimentally Validated Model of the Propeller Force Accounting for Cross Influences on Multi-Rotor Aerial Systems (I), pp. 1163-1169

Bazzana, Barbara	University of Twente
Brantjes, Ralph	University of Twente
Gabellieri, Chiara	University of Twente
Franchi, Antonio	University of Twente

In this paper, we propose a model for the thrust coefficient of propellers that can consider cross-influence between adjacent propellers. The aerodynamic interaction between propellers in multirotor aerial vehicles reduces the thrust they can produce. The influence between propellers depends on their relative positioning and orientation, which are considered by the proposed model. It is validated on measurements collected by a force sensor mounted on a propeller for different configurations of the adjacent propellers in a support structure. In this work, we focus on configurations with small relative orientations. Results show that the proposed model outperforms the traditional constant model in terms of thrust prediction on the data we collected, and it performs better than other models with fewer parameters, being the only one with less than 10% maximum percentage error.

15:40-16:00	FrB1.6

AI Enhanced Structural Health Monitoring with a Multi-Rotor Aerial Vehicle (I), pp. 1170-1176

Zoric, Filip	University of Zagreb, Faculty of Electrical Engineering and Comp
Milas, Ana	University of Zagreb, Faculty of Electrical Engineering and Comp
Petrovic, Tamara	FER
Kovacic, Zdenko	Univ. of Zagreb
Orsag, Matko	University of Zagreb, Faculty of Electrical Engineering and Comp

Roads, bridges, tunnels, railways, and canals are crucial for the transportation of goods and people in modern society. Modern infrastructure is subject to damage and re- quires therefore regular inspection and maintenance to remain safe and functional. While this can be done manually, large parts of the mentioned infrastructure are hardly accessible, which is a main motivational factor for the use of multi- rotor aerial vehicles (MAVs) for inspection and maintenance tasks. MAVs, paired with novel deep learning computer vision techniques, such as instance segmentation, are emerging as an obvious choice for automating certain parts of structural health monitoring (SHM). In this manuscript, we provide an overview of available SHM datasets and how they can be utilized for the task of autonomous crack detection. We use available datasets to train and compare two neural network architectures, for instance segmentation. The segmented crack instances are then localized in a global coordinate frame to perform autonomous mapping of the potentially dangerous infrastructure defects. Experimental studies demonstrate the effectiveness of the proposed SHM approach, which results in precisely localized infrastructure defects marked on the global map

FrB2	**MIKIS 2**
Sensor Fusion (Regular Session)	
Chair: Primatesta, Stefano	Politecnico Di Torino
Co-Chair: Souli, N.	University of Cyprus

14:00-14:20	FrB2.1

Enhanced Altitude Estimation for Unmanned Aerial Vehicles in a GNSS-Denied Environment, pp. 1177-1183

Minervini, Alessandro	Politecnico Di Torino
Primatesta, Stefano	Politecnico Di Torino
Guglieri, Giorgio	Politecnico Di Torino

GNSS-denied environments represent challenging environments for autonomous drones. Ensuring an accurate altitude estimate plays a crucial role in guaranteeing mission efficiency in such scenarios. The literature on autonomous drone localization in GNSS-denied environments relies on visual inertial odometry-based algorithms. However, the reliability of this technology cannot be guaranteed in poor features environments (homogeneous floor, white walls) or in high and low brightness conditions. Even applications adopting loop closure algorithms in combination with visual inertial odometry localization suffer from considerable position estimation drift in challenging environments. This paper aims to propose a methodology to address the altitude estimation problem for drones operating in GNSS-denied environments by combining a V-SLAM algorithm with the altitude measurements from a range finder. To account for ground inconsistencies due to varying terrain or obstacles, we have developed an Adaptive Kalman Filter. The Mahalanobis distance evaluation accomplishes the task of detecting these inconsistencies, enabling the filter to adapt and update states properly even in the presence of inconsistent range finder measurements. Experimental results demonstrate the effectiveness of the proposed solution in mitigating the drift accumulated by a purely V-SLAM algorithm.

14:20-14:40 FrB2.2

Vision-Aided Navigation for UAM Approach to Vertiports with Multiple Landing Pads, pp. 1184-1191

Miccio, Enrico — University of Naples "Federico II"
Veneruso, Paolo — University of Naples "Federico II"
Opromolla, Roberto — University of Naples Federico II
Fasano, Giancarmine — University of Naples "Federico II"
Gentile, Giacomo — Collins Aerospace
Tiana, Carlo — Collins Aerospace

Abstract— The vertiport concept has spread widely as the future aerodrome that will allow Vertical Take-Off and Landing vehicles to operate in complex and congested scenarios, such as those foreseen within the Urban Air Mobility framework. Possible vertiport configurations have been proposed by many government agencies such as the European Union Aviation Safety Agency and the Federal Aviation Administration providing general design and development guidelines. This paper introduces an autonomous visual-aided navigation architecture able to estimate the aircraft state during approaches to vertiports exploiting visual observables gathered by multiple landing patterns. The implemented architecture exploits a Convolutional Neural Network for landing patterns detection; it then performs their discrimination and, for each of them, key points detection and identification to feed a perspective-n-point solver. The resulting pose measurements are input to an Extended Kalman Filter, which also processes data from an Inertial Measurement Unit and a Global Navigation Satellite System receiver. The implemented architecture is tested on synthetic and real data, showing the validity of the pattern discrimination techniques and the performance of the visual-aided filter varying the number of detected patterns along different approach trajectories.

14:40-15:00 FrB2.3

Creating a Robust and Expandable Framework for Cooperative Aerial Robots, pp. 1192-1199

Georgiades, Christos — KIOS Research and Innovation Center of Excellence
Souli, N. — University of Cyprus
Kolios, Panayiotis — University of Cyprus
Ellinas, Georgios — University of Cyprus

This work focuses on the design and development of a microservice-based software framework for multi-drone autonomous systems, that is fault-tolerant, expandable, and easily monitored. The custom framework utilizes the Robot Operating System (ROS) and is applied on onboard embedded devices to command-and-control multiple unmanned aerial vehicles (UAV) in various scenarios, including autonomous flight missions, inter-process communication, as well as measurement fusion for mapping and localization purposes. Further, the proposed framework is implemented and tested in both hardware-in-the-loop simulations and real-world field tests to demonstrate and evaluate its performance. Specifically, the developed prototype is evaluated in scenarios where a swarm of UAVs is tasked to map a predefined area for search-and-rescue purposes and a scenario incorporating faults where one UAV loses its GPS signal and obtains relative positioning with the help of the rest of the UAVs in the swarm.

15:00-15:20 FrB2.4

A Joint Rogue Drone Detection and Tracking Fusing DOA and Passive Radar Measurements, pp. 1200-1207

Souli, N. — University of Cyprus
Kardaras, Panagiotis — University of Cyprus
Kolios, Panayiotis — University of Cyprus
Ellinas, Georgios — University of Cyprus

Advancements in unmanned aircraft systems (UASs) have led to a considerable increase in unlawful operations of these systems over critical infrastructures and public spaces. In this work, a system that is implemented utilizing software-defined radio and signals of opportunity (SOPs) and is based on the fusion of direction of arrival and passive radar sensor measurements is proposed to counter unlawful UAs/drone activities. Specifically, passive radar methodology applied on SOPs (data collection, disturbance cancellation, cross-ambiguity, and constant-false alarm rate detection functions), along with DOA measurements obtained via the multiple signal classification algorithm, are combined to detect, and track the rogue UAS/target in an area under observation. A prototype implementation of the detection-and-tracking system, with the use of small, embedded processing units and the robot operating system is developed and examined in numerous outdoor experiments to thoroughly evaluate its performance.

15:20-15:40 FrB2.5

Deep Learning for Radar Classification, pp. 1208-1215

Holt, Danny — Cranfield University
Guo, Weisi — Cranfield University

Sun, Mengwei	Cranfield University
Panagiotakopoulos, Dimitri	Cranfield University
Warston, Håkan	Saab

Airfield surveillance radars (ASR) face increased challenge of both detecting and classifying non-cooperative airborne targets. Drones are smaller, more diverse, and often operate amongst clutter near the horizon. Traditional radar signal processing is aimed at detecting larger cooperative aircraft that announce their identity and fit within distinctive categories. This is achieved using banks of linear time-invariant processing, thus neglecting any non-linear relationships that may exist between the reflected signal and detected object's properties. Here, we leverage on Recurrent neural networks (RNNs), such as long-short-term memory (LSTM), to learn from sequences of radar data and generate a nonlinear output feature to learn target classes. To date, deep learning has not yet been fully investigated with ASR for object classification. Here, we show that a novel RNN architecture combined with a normalised representation of the analytic radar signal can perform classification tasks. We found that an LSTM layer can discover features from the short running time span of each scan of a target. By concatenating these found features into a new sequence depicting the track over multiple scans, an additional LSTM layer can learn to classify objects. Training of the network was improved by fitting the network to multiple output labels that describe the object. This shows that neural networks can approximate radar linear processing, while also performing nonlinear processing to derive the overall classification. Responses from this architecture demonstrate the ability of deep learning to perform object classification using airfield surveillance radar data. This proposed method can be used as a starting point to explore how explainable the responses and trained model are.

15:40-16:00	FrB2.6

Vision-Based Parameter Estimation of a Slung Load, pp. 1216-1223

Naundrup, Jacob	Aalborg University
Bendtsen, Jan Dimon	Aalborg Univ
la Cour-Harbo, Anders	Aalborg University

This research paper introduces an innovative vision-based technique designed to locate and estimate the position of a tethered slung load relative to an Unmanned Aerial System (UAS). The approach relies on fundamental image processing methodologies, primarily emphasizing accurately determining the pitch of the slung load. This is achieved through a combination of Gaussian filtering, HSV filtering, and Fitzgibbon ellipse detection. An independent measuring device is employed to validate the calculated pitch, adding an extra layer of reliability to the vision software's output. The effectiveness of the proposed method is confirmed through rigorous indoor testing, utilizing measuring devices in controlled conditions. Additionally, outdoor scenarios showcase the reliability and feasibility of the vision-based approach. This approach holds significant promise for enhancing UAS operational capabilities, presenting a cost-effective vision solution for load positioning applications. The outcomes contribute substantially to the advancement of UAS technologies, particularly in missions where precise load positioning is a critical determinant of success, extending the potential applications of vision-based systems in diverse operational environments.

FrB3	**KAM**
UAS Applications IV (Regular Session)	
Chair: Zhang, Youmin	Concordia University
Co-Chair: Shan, Jinjun	York University

14:00-14:20	FrB3.1

Reinforcement Learning Based PID Parameter Tuning and Estimation for Multirotor UAVs, pp. 1224-1231

Sonmez, Serhat	University of Denver
Martini, Simone	University of Denver
Rutherford, Matthew	University of Denver
Valavanis, Kimon P.	University of Denver

A reinforcement learning (RL) based approach is proposed for PID controller fine-tuning and parameter estimation for effective and accurate tracking of a helix trajectory considering realistic flight controller sampling times. RL exploits a Deep Deterministic Policy Gradient (DDPG) algorithm, which is an off-policy actor-critic method. The quadrotor model follows the Newton-Euler formulation and accounts for complete gyroscopic and drag effects. Training and simulation studies are performed using Matlab/Simulink. Performance evaluation and comparison studies are detailed between the hand-tuned, RL-based tuned, and RL-based full estimation of parameters approaches. Results show that full estimation of controller parameters achieves the smallest attitude and position errors, and that both RL-based strategies significantly improve tracking performance compared to the hand-tuned approach.

14:20-14:40	FrB3.2

ROS2-Gazebo Simulator for Drone Applications, pp. 1232-1238

Haridevan, Amal Dev	York University
Kang, Junjie	York University
Yuan, Mingfeng	York University
Shan, Jinjun	York University

This paper introduces ROS2GazeboDrone, a modular C++ and Python-based toolbox based on ROS2 and Gazebo. ROS2GazeboDrone consists of a core module written as a Gazebo System Plugin, that orchestrates the interfaces between Gazebo and Quadrotor. The modular design of the toolbox can be used to test perception, path planning, and control algorithms efficiently. The toolbox can be integrated as a ROS2 node as well as a standalone quadrotor simulator. The decoupled and modular architecture enables the extension of this toolbox to any quadrotor model with minimal modifications. We demonstrate the flexibility of our toolbox through demonstrations.

14:40-15:00	FrB3.3

A Robust UAV-UGV Collaborative Framework for Persistent Surveillance in Disaster Management Applications, pp. 1239-1246

Mondal, Mohammad Safwan	University of Illinois at Chicago
Ramasamy, Subramanian	University of Illinois at Chicago
D. Humann, James	Army Research Laboratory
Dotterweich, James	Army Research Lab
Reddinger, Jean-Paul	Army Research Lab
Childers, Marshal	Army Research Lab
Bhounsule, Pranav	University of Illinois at Chicago

Unmanned Aerial Vehicles (UAVs) are fast, agile, and capable of covering large areas quickly but are constrained by their limited fuel capacities. In contrast, Unmanned Ground Vehicles (UGVs) have longer battery life but move at slower speeds. By combining UAVs with UGVs, which serve as mobile recharging stations, we can harness the strengths of both: UAVs can achieve rapid task execution over extended periods by refueling from UGVs. This synergy makes the collaborative routing of UAVs and UGVs well-suited for modern disaster management applications. However, their varied operational constraints require a sophisticated planning framework to ensure optimized coordination and task execution. In this paper, we introduce a robust multi-agent framework leveraging asynchronous planning to optimize the routes of UAVs and UGVs in a persistent surveillance task, considering their individual limitations like fuel, speed, and charging constraints. The framework is designed to scale effectively with the number of vehicles and accommodates diverse team configurations. The effectiveness of this framework is demonstrated through a simulation of a 4-hour mission covering 30 task points across five different team compositions, showing significant improvements in route efficiency. Additionally, a detailed cost analysis identifies the optimal UAV-UGV team composition by effectively balancing mission performance and cost, thus serving as a valuable tool for optimizing disaster response strategies.

15:00-15:20	FrB3.4

A Fault Detection Method for Power Transmission Lines Using Aerial Images, pp. 1247-1252

Zhang, Yulong	Xi'an University of Technology
Cao, Shaowei	Xi'an University of Technology
Mu, Lingxia	Xi'an University of Technology
Xue, Xianghong	Xi'an University of Technology
Xin, Jing	Xi'an University of Technology
Zhang, Youmin	Concordia University

It is necessary to regularly detect faults to maintain the safety and stability of power lines. Insulators are one of the important electrical components in high-voltage transmission lines. It is extremely necessary to check the working status of insulators regularly. Traditional manual inspection is inefficient because it requires a significant amount of labor costs. In this paper, a method for detecting insulators' missing defect based on aerial images is proposed to address the issue by unmanned aerial vehicle (UAV). Firstly, the improved Faster R-CNN (region-based convolutional neural network) is used to identify and locate insulators in aerial images. Secondly, the U-Net image segmentation network segments insulators from the images. The adaptive threshold segmentation method completely separates the insulator from the background. Then the binary image of the insulator is obtained. Finally, the binary image is converted into a fault curve which is used for determining the missing insulators based on the distribution of the fault curve. By using collected insulator datasets on a 330kV overhead transmission line using a DJI M300 UAV platform and an onboard H20T camera/sensor, the detection accuracy of glass insulators is as high as 0.98 with the proposed algorithm. The positioning accuracy of the proposed algorithm is also higher than other algorithms. This method has high detection accuracy for missing defects in insulators. The experimental results show that compared with similar algorithms, this method has higher accuracy and efficiency.

15:20-15:40	FrB3.5

Fostering UAS Innovations in Sustainable Agriculture and Rural Development in Europe: Assessing the Role of Diversified Stakeholders in the Network, pp. 1253-1260

Bojkova, Viara	NOOSWARE BV
Doornbos, Jurrian	Wageningen University
Valente, João	Spanish National Research Council (CSIC)
Kasimati, Aikaterini	Agricultural University of Athens
Arampatzis, Stratos	NOOSWARE BV

This research explores an interdisciplinary methodology for evaluating the role of diverse stakeholders: including policymakers, technology developers, and agricultural practitioners — in the development and deployment of multi-purpose drone applications within the European Union. The methodological framework, tested on five use cases across Europe, aims to enhance the Uncrewed Aerial Systems (UAS) ecosystem and strengthen local networks within EU member states. Addressing initiatives in livestock & crop monitoring, drone spraying, forest biodiversity, and rural logistics, the study identifies unique network structures, and the varied roles stakeholders play. As part of the ICAERUS Project, this work seeks to unlock the substantial potential and transformative impact of drones in EU agriculture, forestry, and rural areas. Initial findings underscore the critical need to understand the complexity of stakeholder interactions and the socio-technical factors at play. For instance, the analysis revealed that integrating real-time data sharing between drones and farm management systems significantly enhances decision-making processes, exemplifying a socio-technical factor that could accelerate drone innovation. This paves the way for targeted actions such as developing standardized protocols for data exchange and security, aiming to significantly advance drone innovation across a broader context.

15:40-16:00	FrB3.6

Adaptive Quaternion Control for a Quadcopter Vehicle: Real-Time Validation in Presence of Wind Gusts, pp. 1261-1266

Arizaga, Jorge	ITESM
Cariño Escobar, Jossué	ONERA
Castaneda, Herman	Tecnologico De Monterrey
Mercado Ravell, Diego Alberto	Center for Research in Mathematics CIMAT
Castillo, Pedro	Université De Technologie De Compiègne

An adaptive control for a quadcopter aerial vehicle exposed to aggressive wind gusts is presented in this paper. The control scheme is composed by two parts; firstly, the attitude dynamics is robustly stabilized using a controller based on the quaternion formulation. Then, a translational flight control law with adaptive properties is designed using the sliding mode approach. The stability analysis of the whole system is proved using the Lyapunov theory. The performance of the closed-loop system is validated in real-time experiments and for validating the adaptive and robust properties of the controller, strong wind gusts are applied during flight tests. A video and some graphs, obtained from these experiments, illustrate the effectiveness and robustness of the proposed control strategy.

FrB4	**DILOVO**
Technology Challenges (Regular Session)	
Chair: McLain, Tim	Brigham Young University
Co-Chair: Herfray, Benjamin	McGill University

14:00-14:20	FrB4.1

Compact Docking Station for Sub-150g UAV Indoor Precise Landing, pp. 1267-1274

Martin, Thomas	INRIA
Roman Blanco, Jefferson	LCFC/University of Lorraine
Mouret, Jean-Baptiste	INRIA
Raharijaona, Thibaut	University of Lorraine

To be used at their full potential, sub-150g drones need to be integrated into a "foolproof" deployment system, from take-off to landing. In this paper, we introduce a compact (less than 15x15 cm) docking station that could fit in a suitcase. To achieve accurate drone localization, we evaluated various systems (Optitrack Duo/Trio, Bitcraze's radio-based system) and found that a vertically mounted Lighthouse sensor from the HTC Vive system offers a few centimeters of accuracy while being significantly smaller than multi-camera systems. Our final docking station design incorporates this sensor, along with an actuated landing pad that retracts from the sensor's field of view during landing. This novel landing system paves the way for the use of small indoor drones by professionals without the need for extensive drone training.

14:20-14:40	FrB4.2

Comparative Analysis of Linear and Nonlinear Kalman Filters for Airflow Estimation in UAVs, pp. 1275-1284

Clough, Justin	The University of Kansas
Carlson, Megan	The University of Kansas
Keshmiri, Shawn	University of Kansas

In the past three decades, numerous works have been done on the applications of linear and nonlinear Kalman filters in estimating crewed and uncrewed aircraft airflow angles. In uncrewed autonomous aircraft, the flight envelope protection (FEP) algorithms play a vital role in ensuring the safety of the aircraft during flight. The FEP heavily relies on accurate estimations of angle of attack and sideslip angles. In addition to safety, autonomous controller performance can significantly degrade due to poor airflow estimations. Compared to large transport or general aviation aircraft, autonomous aircraft are much lighter, fly lower, and fly slower, which makes them more vulnerable to external disturbances. This work presents the theoretical framework of both linear and nonlinear Kalman filters. It showcases the design process of five different Kalman filters using the 6DoF simulation environment in the presence of sensor noise and external disturbances in the form of the Dryden wind disturbance model. Different Kalman filter designs are assessed using actual flight test data for a realistic evaluation process. Among the five different designs, the Ensemble Kalman filter demonstrated the lowest mean normal of the covariance matrix, indicating superior estimation accuracy. Given the stringent computation power onboard uncrewed aircraft, special attention is given to the computational overhead of each design.

14:40-15:00	FrB4.3

Velocity Planning with Multi-Objectives in Displacement-Time Graphs Using Deep Reinforcement Learning, pp. 1285-1291

Wang, Liyang	COMAC
Bronz, Murat	ENAC

This paper presents a novel velocity planning method in displacement-time graphs with multiple constraints and optimization goals using deep reinforcement learning. The method formulates the velocity planning problem as a reinforcement learning task with state representation including time, position, velocity, acceleration, and distances to each obstacle triangle representative. The action space is discretized within allowable accelerations, and the kinematics ensure velocity constraints during state transitions. The advantage of this method lies in its independence from scene-specific tuning and exhibiting robustness in various complex scenarios. Comparative analysis demonstrates a 100% success rate, along with superior computational efficiency when contrasted with the baseline approach, while also exhibiting better comfort performance. It offers a valuable alternative for velocity planning in robotics and autonomous vehicles, showcasing deep reinforcement learning's potential in practical robotics applications.

15:00-15:20	FrB4.4

Robust IR-Based Pose Estimation for Precision VTOL Aircraft Landing in Urban Environments, pp. 1292-1300

Akagi, David	Brigham Young University

McLain, Tim | Brigham Young University
Mangelson, Josh | Brigham Young University

This paper presents a novel pose estimation framework that provides high-accuracy localization for vertical take-off and landing aircraft in settings where GPS is unreliable or unavailable. The proposed framework utilizes a sparse constellation of infrared lights that can be robustly identified and associated in the presence of outliers and occlusions, making it suitable for use in realistic urban environments. This is enabled by constellation designs that exploit properties of invariance under projective transformations. Flight test results demonstrate that the framework can run in real-time at speeds of over 30 Hz while providing pose information at decimeter-level accuracy at ranges of over 100 m from the landing site.

15:20-15:40 | FrB4.5

Smart Self-Diagnosis Method for GPS Attacks and Safety Faults in UAVs, pp. 1301-1308

Ferrão, Isadora | University of São Paulo
Luiz de Oliveira, André | Universidade Federal De Juiz De Fora
Espes, David | Université De Bretagne Occidentale
Dezan, Catherine | Université De Bretagne Occidentale
Branco, Kalinka Regina Lucas Jaquie Castelo | University of São Paulo

Unmanned aerial vehicles (UAVs) have been used in a variety of applications in safety-critical domains such as logistics, transportation, and defense. However, safety assurance is needed for the widespread development and operation of UAVs in urban areas where a failure may lead to physical harm to people, environment, or property. Since UAVs are highly interconnected, security is an important concern for the acceptance of safety-critical UAV applications. Thus, it is needed to ensure that UAVs are protected from attacks, e.g., Global Position System (GPS) signal spoofing, and unauthorized manipulation of flight controls, caused by malicious external agents aiming to compromise system/data confidentiality, integrity, or availability. Artificial Intelligence techniques such as Machine Learning classifiers can be used to support the identification of UAVs attacks. This study presents the development of safety and security diagnostic methods for UAVs. Two multiclass approaches are proposed, focusing on identifying safety-related failures and security threats such as GPS spoofing and jamming attacks. Various machine learning algorithms are employed, and evaluation metrics demonstrate high accuracy rates across models. The study underscores the importance of addressing both safety and security aspects in UAVs operations and provides pre-processing code for reproducibility. The developed methods contribute to enhancing UAV resilience and understanding safety and security measures in unmanned aerial operations.

15:40-16:00 | FrB4.6

Development of a CFD Model of Propeller Slipstream, pp. 1309-1318

Herfray, Benjamin | McGill University
Nahon, Meyer | McGill University

The growing interest in electric power trains for aircraft has led to new aircraft designs for air taxis and Unmanned Aerial Vehicles (UAVs). Electric powertrains allow aircraft designers to consider novel propulsion layouts such ones in which many motors/propellers are distributed along the wing's leading edge, known as Distributed Electric Propulsion (DEP). This configuration confers several advantages, including the mitigation of airflow separation. Understanding the wake of a propeller can allow us to develop a better understanding of the dynamical behaviour of DEP aircraft, where large parts of the wings are immersed in the propeller slipstream, which can have a large influence on the forces generated by the wing. In the present work, we describe a method for simulating the wake of a given propeller in the OpenFOAM Computational Fluid Dynamics (CFD) package. The propeller model uses body forces within a finite propeller region, acting as a momentum source for fluid passing through it. Simulations using this method were performed for various propeller geometries, rotation rates, and freestream velocities, and results were compared with experimental measurements from the literature, yielding good agreement.

FrC1 | **MIKIS 1**

Aerial Robotics in Inspection and Maintenance Operations II (Invited Session)

Chair: Chaikalis, Dimitris | New York University
Co-Chair: Castillo, Pedro | Université De Technologie De Compiègne
Organizer: Gabellieri, Chiara | University of Twente
Organizer: Silano, Giuseppe | Czech Technical University in Prague
Organizer: Selvaggio, Mario | University of Naples Federico II

16:30-16:50 | FrC1.1

Design and Experimental Validation of a Marsupial Long-Endurance UAV-UGV System (I), pp. 1319-1324

Martinez-Rozas, Simon | Universidad De Antofagasta
Alejo, David | University Pablo De Olavide
Carpio Jiménez, José Javier | Universidad Pablo De Olavide
Merino, Luis | Universidad Pablo De Olavide
Caballero, Fernando | University of Seville

Over the last decades, we have experienced an exponential growth in the use of Unmanned Aerial Vehicles (UAVs) for inspection operations. However, the reduced flight autonomy of electric powered UAVs can limit their applicability in long duration operations. In this paper, we propose a marsupial system composed of a UAV and a Unmanned Ground Vehicle (UGV). The system is made with off-the-shelf components that can greatly extend the flight duration of the UAV by powering it from the UGV using a tether and reducing the mobility limitations by the coordinated motion of the system. We present hardware design, making emphasis in the decisions made and

presenting different alternatives depending on the application. Moreover, the software architecture for operating the device, based on the Robotic Operating System (ROS) is presented. Finally, the system is validated in experiments lasting more than one hour.

16:50-17:10 FrC1.2

Optimization-Based Compliant Controller for Physical Human-Aerial Manipulator Interaction, pp. 1325-1331

Chaikalis, Dimitris	New York University
Tzes, Anthony	New York University Abu Dhabi

The use of aerial manipulators in mixed human-robot environments necessitates the capacity for safe interactions between them. This work is concerned with enabling human-aided navigation of unmanned aerial manipulators, allowing human operators to effectively take over the path planning task of an aerial manipulator platform, by exerting appropriate forces on its end-effector. A guaranteed-compliance model-based optimization controller is developed for the system's articulated arm, ensuring that the arm can comply with forces and moments on its end-effector, while using control barrier functions (CBFs) to always maintain non-singular configurations. Another optimization-based controller is designed for the aerial vehicle, appropriately interpreting the robot arm end-effector motions in order to comply with human-induced intended poses, with CBFs included to ensure measured forces remain bounded, for additional safety. Experimental studies are included, showcasing the capacity of the presented control framework in enabling human-guided navigation for autonomous aerial manipulators.

17:10-17:30 FrC1.3

Sarax: An Open-Source Software/Hardware Framework for Aerial Manipulators (I), pp. 1332-1339

Alharbat, Ayham	Saxion University of Applied Sciences
Dion, Zwakenberg	Saxion University of Applied Sciences
Esmaeeli, Hanieh	Saxion University of Applied Sciences
Mersha, Abeje Yenehun	Saxion University of Applied Sciences

The use of Multi-Rotor Aerial Vehicles (MRAVs) in tasks that require physical interaction has been an active research field in the last decade which resulted in an increasing interest in Aerial Manipulators (AMs). This raises many challenges in the modeling, control, perception, and planning of these robots. However, designing and realizing an AM testbed is a complicated multi-disciplinary task, and there is a lack of standardization in the relatively new field of AMs. For this purpose, we introduce Sarax, an open-source hardware and software framework tailored for AMs research and innovation. The software of Sarax is built on top of open-source projects such as the Robot Operating System (ROS) and PX4 Autopilot, while the hardware is designed to be customizable, modular, and easily scalable through parameterized models. We verified and validated the proposed framework through indoor and outdoor experiments. We aim to open the door to accelerate AMs research and innovation, allow researchers and developers to focus on their core contributions, and take AMs technology to a higher readiness level.

17:30-17:50 FrC1.4

Streamlined Indoor UAVs Localization Using a Dense and Size-Heterogeneous Tags Map (I), pp. 1340-1346

Bertoni, Massimiliano	University of Padova
Montecchio, Simone	University of Padova
Michieletto, Giulia	University of Padova
Oboe, Roberto	University of Padova
Cenedese, Angelo	University of Padova

A significant challenge in the employment of UAV platforms for indoor inspection and maintenance operations lies in the problem of finding a portable and cost-effective way to accurately localize aerial vehicles in GNSS-denied environments. Focusing on the visual-based positioning paradigm, we outline a pose estimation procedure whose accuracy is achieved by leveraging the potential offered by a dense and size-heterogeneous map of tags. The proposed indoor UAVs localization rests on i) hierarchical tag selection, ii) outlier removal, and iii) multi-tag estimation averaging, to facilitate visual-inertial reconciliation. We assess the performance of the outlined positioning system through ad-hoc experimental tests that highlight the localization accuracy improvement as compared with other existing state-of-the-art solutions.

17:50-18:10 FrC1.5

Quaternion-Based Observer Control for Multirotor UAVs, an Application to Unactuated Grasping, pp. 1347-1353

Gandulfo Cipres, Diego Jose	Tecnologico De Monterrey
Varela, Alberto	Tecnologico De Monterrey
Castillo, Pedro	Université De Technologie De Compiègne
Abaunza, Hernan	Tecnologico De Monterrey

A novel approach for aerial drone control in object pickup tasks is presented. The methodology integrates quaternion-observer control to address the challenge of variable mass during object interaction. A specialized non-actuated gripper designed explicitly for aerial drones enhances their ability to grasp objects efficiently. Real-time tests validated the effectiveness and feasibility of the proposed solution. The experiments demonstrated the robustness and adaptability of quaternion-observer control in compensating for variable mass during object pickup tasks. Additionally, the practical utility of the non-conventional gripper design under real-world conditions emphasized its relevance in aerial manipulation scenarios.

FrC2 **MIKIS 2**

Industrial Inspection and Maintenance with Aerial Manipulators (Invited Session)

Chair: Ollero, Anibal Universidad De Sevilla - Q-4118001-I

Co-Chair: Rafee Nekoo, Saeed	Escuela Técnica Superior De Ingeniería, Universidad De Sevilla
Organizer: Gonzalez-Morgado, Antonio	Universidad De Sevilla
Organizer: Fumagalli, Matteo	Danish Technical University
Organizer: Trujillo, Miguel Ángel	Center for Advanced Aerospace Technologies (CATEC)
Organizer: Rodriguez Rivero, Jacob	Company

16:30-16:50 FrC2.1

Assisted Physical Interaction: Autonomous Aerial Robots with Neural Network Detection, Navigation, and Safety Layers (I), pp. 1354-1361

Berra, Andrea	(FADA CATEC) Fundacion Andaluza Para El Desarrollo Aeroespacial
Sankaranarayanan, Viswa Narayanan	Luleå University of Technology, Sweden
Seisa, Achilleas Santi	Lulea University of Technology
Mellet, Julien	University of Naples Federico II
Udayanga, Kashita Niranjan Gangoda Withana Gamage	DTU, Denmark
Satpute, Sumeet	Lulea University of Technology
Ruggiero, Fabio	Università Degli Studi Di Napoli "Federico II"
Lippiello, Vincenzo	Universita' Di Napoli Federico II
Tolu, Silvia	Technical University of Denmark
Fumagalli, Matteo	Danish Technical University
Nikolakopoulos, George	Luleå University of Technology, Sweden
Trujillo, Miguel Ángel	Center for Advanced Aerospace Technologies (CATEC)
Heredia, Guillermo	University of Seville

The paper introduces a novel framework for safe and autonomous aerial physical interaction in industrial settings. It comprises two main components: a neural network-based target detection system enhanced with edge computing for reduced onboard computational load, and a control barrier function (CBF)-based controller for safe and precise maneuvering. The target detection system is trained on a dataset under challenging visual conditions and evaluated for accuracy across various unseen data with changing lighting conditions. Depth features are utilized for target pose estimation, with the entire detection framework offloaded into low-latency edge computing. The CBF-based controller enables the UAV to converge safely to the target for precise contact. Simulated evaluations of both the controller and target detection are presented, alongside an analysis of real-world detection performance.

16:50-17:10 FrC2.2

Integration of Customized Commercial UAVs with Open-Source Tools in a Heterogeneous Multi-UAV System for Power-Lines Inspection (I), pp. 1362-1369

Gil Castilla, Miguel	University of Seville
Caballero, Alvaro	University of Seville
Maza, Ivan	Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla - Q-4118001-I

This paper presents our approach to the power-lines inspection application with a team of multiple heterogeneous UAVs that provides the required flexibility to tackle different use cases such as fault detection or periodic inspection. Our solution required proper integration of several commercial UAVs customizing their hardware and building a software architecture based on open-source tools under the ROS (Robotic Operating System) framework to enhance adaptability, specialization, and overall mission effectiveness. The team, comprising fixed-wing VTOLs and multicopters, collaboratively executes fully autonomous mission for monitoring the aerial powerlines, the transmission towers and their components in real-time. Heterogeneity is crucial to tackle different use cases, since for instance the fixed-wing VTOL can provide fast response for the detection of faults, while the agility and precision of multicopters facilitate detailed periodic inspections. The paper presents validation results of our approach both in simulation and in real power-lines inspection campaigns.

17:10-17:30 FrC2.3

Finite-Time and Infinite-Time Horizon State-Dependent Riccati Equation for Swinging-Up and Control of a Rotary Drone Pendulum (I), pp. 1370-1376

Rafee Nekoo, Saeed	Escuela Técnica Superior De Ingeniería, Universidad De Sevilla
Yao, Jie	University of Minnesota at Twin Cities
Ollero, Anibal	Universidad De Sevilla - Q-4118001-I

The control, prototyping, and experimentation of rotor-based systems (aerial robotic platforms) were highlighted recently for rotation around pipes for inspection, measurement, and maintenance. The application of the rotary inspection comes from chemical plants and the oil and gas industry where in some cases, access to all perimeters of the pipes is difficult. Rotary aerial systems then are good candidates. Here in this work, a novel system is proposed for rotary inspection based on a two-link rotary drone pendulum. The modeling of the system released highly nonlinear dynamics. Finite-time and infinite-time horizon state-dependent Riccati equation (SDRE) were chosen to control the system, both in the domain of nonlinear optimal control. These nonlinear controllers are suitable for handling the dynamics and the finite horizon design offers a rapid response for swinging up and stabilization around the pipe. Solving this challenge in control enables us to move forward with the design and implementation of the system on a real setup and prototype. The Simulation and comparison of finite-time (state-dependent differential Riccati equation (SDDRE)) and infinite-time SDRE were done; it showed successful regulation with faster response and less error for the finite-time method.

17:30-17:50 FrC2.4

Petrochemical Industry Aerial Robotic Inspection: A Novel Concept for Landing and Deploying Robots on Pipes (I), pp. 1377-1384

Montes-Grova, Marco Antonio	Center for Advanced Aerospace Technologies (CATEC)
Ortuno Conde, Jaime	CATEC
Tejero-Ruiz, David	Advance Center for Aerospace Technologies (CATEC)
Olmedo, Jesús	CATEC
Perez-Grau, Francisco Javier	(FADA CATEC) Fundación Andaluza Para El Desarrollo Aeroespacial
Trujillo, Miguel Ángel	Center for Advanced Aerospace Technologies (CATEC)
Viguria, Antidio	FADA-CATEC

This paper introduces a hybrid aerial robot for Non-Destructive Testing (NDT) thickness petrochemical pipes inspection and a novel method for recognizing and landing on pipes in areas where Global Navigation Satellite System (GNSS) signals are degraded. In these environments, the inspection of pipes at height presents a high risk for the workers. We have addressed the issue of landing safely on pipes by implementing tilted rotors and a force control technique. Due to the type of environment, a LiDAR-Inertial Odometry has been implemented for aircraft localization. In addition, pipes are detected and tracked using a fusion of some of the onboard sensors: a depth camera and a 2D LiDAR. The outcome is an unmanned aerial vehicle with the capability of deploying a robotic crawler on pipes at height while performing safe landing and takeoff. A demonstration of autonomous landing in an outdoor controlled environment can be found in https://youtu.be/yYRzDUkc_Bk.

17:50-18:10	FrC2.5

Open-Source Web-Based Ground Control Station for Long-Range Inspection with Multiple UAVs (I), pp. 1385-1392

Poma, Aguilar, Alvaro Ramiro	University of Seville
Caballero, Alvaro	University of Seville
Maza, Ivan	Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla - Q-4118001-I

This paper presents a web-based ground control station (GCS) designed to manage a fleet of heterogeneous Unmanned Aerial Vehicles (UAVs) based on a client-server architecture. The primary focus of the developed software is to efficiently oversee and monitor multiple UAVs engaged in long-range missions. The GCS emerges as a scalable solution compatible with various autopilots using the Robotic Operating System (ROS) framework, featuring a user-friendly interface crafted to handle numerous UAVs seamlessly without overwhelming the operator. It allows multiple operators to assign different tasks to the UAV, monitor telemetry, view images from onboard cameras, and control the flight through the GCS. The implemented interface boasts a minimalist design, allowing users to effortlessly navigate and control multiple UAVs. This design philosophy aims to enhance user experience while ensuring effective mission management. The GCS enables connection with external programs, facilitating seamless integration with third-party applications.

FrC3	**KAM**
Energy/Environment/Reliability (Regular Session)	
Chair: Bertolani, Giulia	Università Di Bologna
Co-Chair: Cooper, Thelonious	MIT

16:30-16:50	FrC3.1

Airspace Situational Awareness: Proposed Airspace Safety Concepts & State-Of-The-Art Review of UAS Aircraft Detection Technologies, pp. 1393-1400

Maalouf, Guy	University of Southern Denmark
Jepsen, Jes Hundevadt	University of Southern Denmark
Jensen, Kjeld	University of Southern Denmark

The integration of UAS into lower airspace requires trustworthy Detect and Avoid (DAA) capabilities, which hinge on robust Airspace Situational Awareness (ASA) technologies. This paper introduces a structured approach to effectively address and simplify the challenges of ASA for UAS. It introduces Operational Classes (OCs) for categorising airspace risks, System Configurations (SysCons) for grouping distinct system structures, and DAA Strategies, based on ACAS-Xu, for improving UAS safety and operational efficiency through proactive and reactive measures. Furthermore, it explores diverse detection technologies for both cooperative and non-cooperative aircraft, analysing their strengths and limitations, and recommends which technologies to use for various SysCons.

16:50-17:10	FrC3.2

Enhancing Battery Efficiency through Semi-Markov Decision Processes in Task Allocation for UAVs, pp. 1401-1408

De Alba Franco, Abraham	Tecnologico De Monterrey
Flores Madriz, Alejandro	Tecnologico De Monterrey
Garcia Maya, Brenda Ivette	School of Engineering and Sciences, Tecnologico De Monterrey
Abaunza, Hernan	Tecnologico De Monterrey

This research introduces a Semi-Markov Decision Process (SMDP) approach to task allocation for Unmanned Aerial Vehicles (UAVs) by considering the stochastic behavior of battery levels. The SMDP allows the UAV to dynamically allocate tasks based on its current battery state and the time spent in each state. We compare the SMDP method with a manually assigned task sequence and demonstrate a significant reduction in completion time for a set of predefined tasks. The SMDP optimally assigns tasks, considering the stochastic nature of battery levels, resulting in improved efficiency, and eliminating uncertainties associated with human allocation. The findings

underscore the benefits of incorporating SMDP in UAV task management, especially in scenarios dependent on real-time battery levels.

17:10-17:30	FrC3.3

Unveiling the Impact of Drone Noise on Wildlife: A Crucial Research Imperative, pp. 1409-1416

Afridi, Saadia	Avy B.V
Hlebowicz, Kasper	Wildlife Ecology and Conservation, Wageningen University and Res
Cawthorne, Dylan	University of Southern Denmark
Schultz, Ulrik Pagh	University of Southern Denmark

Unmanned Aerial Vehicles, commonly known as drones, have become integral across various industries, ranging from photography and surveillance to scientific research. While their applications offer numerous benefits, the noise generated by drones poses a potential threat to the well-being of wildlife. Using a systematic literature review, we examine a wide range of sources to gain insights into the current state of knowledge on the impacts of drones on wildlife, with a particular focus on noise. The literature review reveals a significant research gap and highlights the need for a more comprehensive understanding of the impact of drone-induced noise on animal and ecosystem behavior. This paper advocates for concerted efforts to address the issue of drone noise on animals. It raises a fundamental question: Can we design drones to minimize noise and responsibly incorporate them into wildlife research?

17:50-18:10	FrC3.5

A Stochastic Compound Failure Model for Testing Resilience of Autonomous Fixed-Wing Aircraft I: Formulation and Simulation, pp. 1425-1431

Cooper, Thelonious	MIT
Ravela, Sai	Massachusetts Institute of Technology

This paper presents a Markov chain model to dynamically emulate the effects of adverse (failure) flight conditions on fixed-wing, autonomous aircraft system actuators. It implements a PX4 Autopilot flight stack module that perturbs the attitude control inputs to the plane's actuator mixer. We apply this approach in simulation on a fixed-wing autonomous aircraft to test the controller response to stochastic compound failures on a range of turning radii. Statistical measures of the differences between target and simulated flight paths demonstrate that a well-tuned PID controller remains competitive with adaptive control in a cascading, compound, transient failure regime.

17:50-18:10	FrC3.5

Hierarchical Control Design for a Helicopter-Payload System for Water Monitoring, pp. 1417-1424

Bertolani, Giulia	Università Di Bologna
Giulietti, Fabrizio	Università Di Bologna
de Angelis, Emanuele Luigi	University of Bologna

The integration of helicopters with payloads for environmental monitoring applications presents a unique set of challenges. This paper proposes a hierarchical control scheme designed to address the complexities inherent in controlling a system composed of a helicopter and a payload dragged into water through a cable. The hierarchical architecture consists of multiple layers, each responsible for different aspects of control, including precise trajectory tracking, payload, and helicopter control. At the higher level, a waypoints tracking controller generates reference velocities for the mid-loop. The intermediate level comprises a PID plus sliding mode control strategy tailored to ensure reference speed tracking for both the payload and the helicopter. The inner loop regulates the helicopter's attitude, maintaining its stability while moving the payload into the water. The effectiveness of the proposed hierarchical control scheme is validated through simulations. Results demonstrate waypoints tracking accuracy, thereby enabling more reliable and efficient monitoring missions in aquatic environment. By proposing a hierarchical control scheme for a helicopter-payload system, this research contributes to the advancement on the use of UAVs for environmental monitoring, introducing the use for small-scale helicopters in water quality monitoring.

FrC4	**DILOVO**
Manned/Unmanned Aviation (Regular Session)	
Chair: Scukins, Edvards	SAAB Aeronautics
Co-Chair: Nacional, Escuela	Escuela Politécnica Nacional

16:30-16:50	FrC4.1

Digital Airworthiness Certification: Opportunities for Unmanned Aircraft Systems, pp. 1432-1437

Cook, Stephen	Northrop Grumman Aeronautics Systems

One of the challenges for integration of unmanned aircraft systems (UAS) into national and international airspace systems is the requirement for the UAS to be certified as airworthy for its configuration, use, and environment. Traditionally aircraft certification has largely been a labor-intensive exercise that involved the showing of compliance to airworthiness requirements through analysis, simulation, and test with results documented in reports. The finding of compliance by the appropriate regulatory agencies involves thoroughly reading the reports and arriving at a conclusion as to whether the reports are sufficient or if more data is required. For UAS, this process is particularly challenging due to the novel aspects of their design and operation. Fortunately, recent developments in digital transformation of the aerospace industry and in development of industry consensus standards for UAS have opened opportunities for UAS to use a digital airworthiness certification approach. This approach has three stages – a future without paper, a future without artifacts, and a future without exhaustive physical testing. The opportunities and challenges associated with each future are discussed in the context of unmanned aircraft systems.

16:50-17:10	FrC4.2

Sanctions and Norwegian Drone Law - Legal Analysis, pp. 1438-1445

Fortonska, Agnieszka	University of Silesia

The article analyzes the controversial issue of the aircraft flight ban against Russia and its possible extension to unmanned aircraft. Considering the international restrictions imposed on Russia in response to its aggressive actions against Ukraine, the author examines the arguments for and against including drones in the scope of sanctions. The aim of the article is to identify the potential legal consequences of such an extension of the flight ban. By analyzing case law, the author tries to provide a comprehensive view of this issue, paying attention to national law and European Union law.

17:10-17:30	FrC4.3

Deep Learning Based Situation Awareness for Multiple Missiles Evasion, pp. 1446-1452

Scukins, Edvards	SAAB Aeronautics
Klein, Markus	SAAB Aeronautics
Kroon, Lars	SAAB Aeronautics
Ögren, Petter	KTH

As the effective range of air-to-air missiles increases, it becomes harder for pilots and Unmanned aerial vehicle (UAV) operators to maintain the Situational Awareness (SA) needed to keep their aircraft safe. In this work, we propose a decision support tool to help pilots in Beyond Visual Range (BVR) air combat scenarios assess the risks of different options and make decisions based on those. Building upon earlier research that primarily addressed the threat of a single missile, we extend these ideas to encompass the complex scenario of multiple missile threats. The proposed method uses Deep Neural Networks (DNN) to learn from high-fidelity simulations and provide the pilots with an outcome estimate for a set of different strategies. Our results demonstrate that the proposed system can manage multiple incoming missiles, evaluate a family of options, and recommend the least risky course of action while accounting for all incoming air-to-air threats.

17:30-17:50	FrC4.4

Open-Source Software-In-The-Loop Strategies for Realistic UAV Monitoring Applications, pp. 1453-1460

Chamorro Hernandez, William Oswaldo	Escuela Politecnica Nacional
Toapanta, Francisco	Escuela Politecnica Nacional
Loyaga Carranza, Erick Steven	Escuela Politécnica Nacional
Carrillo Aguaisa, Andrey David	Escuela Politecnica Nacional
Nacional, Escuela	Escuela Politécnica Nacional

The rise in UAV capabilities has significantly boosted aerial monitoring activities in recent years. This surge in unmanned aerial vehicles has increased attention towards monitoring tasks in vital areas, such as urban spaces for security, surveillance, or Internet of the Things applications. In this sense, we propose an open-source software-in-the-loop approach that integrates the complete navigation experience, accounting for potential wind-related effects, and providing realistic 3D modeling of scenarios encompassing open spaces in city landscapes. Our work introduces a wind perturbation estimation strategy, which models the wind effect as an external force along the Zaxis based on altitude variations from real flights. Validation was conducted using real data flights with a quadrotor aiding the navigation with Ardupilot and QgroundControl as a ground station. To complement the experiments, we include a small test with a fixed-wing plane to assess the software-in-the-loop accuracy on larger trajectories. Results demonstrate successful tracking of altitude variations, yielding errors below 10% relative to the home position in experiments with average trajectory lengths of 150 m in two scenarios in Quito. The software-in-the-loop simulation aimed to replicate wind conditions specific to the date and time of real data acquisition, providing a platform to emulate possible improvements and assess UAV performance before deployment in actual missions. This research not only contributes to the optimization of monitoring capabilities but also serves as a valuable tool for assessing UAV missions in diverse and dynamic environments.

17:50-18:10	FrC4.5

Including Unmanned Aircraft Systems in the Existing Scheme of Emergency Medical Services in the EU, pp. 1461-1464

Savić, Iva	Faculty of Law of University of Zagreb

The usage of unmanned aircraft systems (UAS) in medical and other emergency services has been on the rise. With many (test) projects and missions completed that showed the potential of UAS usage in those situations, this paper explores the regulatory framework and possible inclusion of UAS in emergency medical services in the European Union, especially in regard to the existing helicopter emergency medical services (HEMS) and its regulation.

ICUAS '24 Key Word Index

ICUAS '24 Author Index