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State-of-the-art and recent developments in unmanned aviation

Contact us:

4550 E. Cherry Creek S. Drive, Unit 305
Denver, CO 80246 - USA
Ph: (303) 862-6548 Cell: (303) 718-3097

Kimon P. Valavanis
Founder & President
kvalavanis@icuas.com

Nadia Danezou
Art, Production & Media
danezou@icuas.com

EDITORIAL

Dear colleagues and readers:

The Fall 2024 issue of the *eMagazine* presents information about the upcoming **ICUAS 2025**, which will take place in Charlotte, NC, USA, on May 14-17. It also includes a contributed paper entitled "Through-Window Home Aerial Parcel Delivery with Fully Actuated Multi-Rotor: Users Perspective from Flight Tests in Indoor Testbed" co-authored by Antonio Gonzalez-Morgado, Alejandro Suarez, and Anibal Ollero. The authors are with GRVC Robotics Lab, University of Seville, Spain.

ANNOUNCING ICUAS 2025

The 2025 International Conference on Unmanned Aircraft Systems will take place on May 14-17 in Charlotte, NC, the second-largest banking center in the United States. The Conference is sponsored by the University of North Carolina at Charlotte (UNC Charlotte) and the University of Denver. The venue is on the campus facilities of the University, UNCC.

This year, the Conference centers around civil and public domain applications, and on the impact of unmanned aviation to society. Although there is a plethora of different topics that will be discussed, emphasis is given to:

1) Real-time aerial manipulation
2) Multi-mode platforms
3) Design for resiliency and autonomy
4) Human factors and ethical AI as applied to unmanned aviation
5) Learning-based navigation and control
6) Regulations for integration into the national airspace.

University of North Carolina at Charlotte

As in previous years, an integral part of the annual Conference is the *UAV Competition*, which is student-focused and student-centered, offering unique opportunities for students to test and compare their skills with those of their peers, worldwide. The competition is organized in two stages: simulation qualifiers and in-person finals during the conference.

ICUAS 2025 is a 'physical presence only' four-day event. May 14-16 spans the three-day technical conference, while May 17 is devoted to Workshops and Tutorials.

The important dates to remember are as follows:

February 4, 2025:......................Full Papers / Invited Sessions / Tutorial Proposals Due
February 10, 2025:....................UAV Competition: simulation-based scenario
March 25, 2025:........................Acceptance / Rejection Notification
March 25 – April 10, 2025:........Early Registration and Upload Final, Camera Ready Papers

Details about the Conference may be found at www.uasconferences.com.

Charlotte, NC

THROUGH-WINDOW HOME AERIAL PARCEL DELIVERY WITH FULLY ACTUATED MULTI-ROTOR: USERS PERSPECTIVE FROM FLIGHT TESTS IN INDOOR TESTBED

ANTONIO GONZALEZ-MORGADO, ALEJANDRO SUAREZ, AND ANIBAL OLLERO
GRVC ROBOTICS LAB, UNIVERSITY OF SEVILLE
mantonio@us.es, asuarezfm@us.es, aollero@us.es

Abstract. This paper reports the results from a user's survey conducted to evaluate qualitatively different aspects in the application of a fully-actuated multi-rotor platform equipped with a front basket for the delivery of light parcels like medicines through the window of the user. The survey, comprising 14 rating questions, involved 18 participants (11 men and 7 women) in four ranges of age with different levels of knowledge and experience in aerial robotics. The experiments were conducted in a representative scenario within an indoor testbed. The results reveal that participants found the proposed aerial delivery service fast, safe, easy to use, and comfortable, reporting other particular aspects derived from the analysis and comparison of the responses.

1. INTRODUCTION

Last-mile delivery robots [1] have received significant attention in last years due to the expected benefits that these platforms may provide in terms of shorter delivery times, reduction of greenhouse emissions, cost, and road traffic, taking into account the high demand of delivery services associated to the increase in e-commerce. Autonomous delivery robots (ADRs) and unmanned aerial vehicles (UAVs) are considered nowadays key solutions in the parcel transportation [2] and delivery [3] [4] problem.

As analysed in [1], the development and application of autonomous delivery robots involves four main topics: 1) operation aspects, as detailed in [5], related to the way the system is deployed, as well as the cost, time, and other factors, 2) infrastructure required to allow or facilitate the implementation of the delivery robot [6], 3) regulatory frameworks that must be adhered to existing regulation for both ground and aerial vehicles [7] on each country or region, and 4) acceptance [1][8] by users and society of using this kind of automated solutions in their environment. Several user surveys carried out rely on theoretical models like the Health Belief Model or the Task-Technology Fit Model, considered in [6] to analyse the degree of acceptance of users towards ADRs. In many cases, involved participants do not have any direct interaction with the evaluated robot. Other studies like [9] derive a model of the human behaviour from the experience reported by users of delivery robots, determining hedonic and utilitarian factors that serve to derive the model. The work presented in [10] relate technological and health belief factors with the acceptance of customers in the context of the COVID pandemic.

The use of drones for autonomous home delivery was proposed ten years ago in preliminary works like [11], involving problems like safe and reliable navigation [12]. Comparative analysis [13] reveal that drones are more effective for reducing the pollution in rural areas than in urban environments. The use of drones for the delivery of medicines represents a case of particular interest [14], taking into account the difficulty of mobility of the elderly for example, or the necessity to provide fast response in emergency situations. Some designs have been proposed, like the use of fiducial markers for dropping-off the parcel [15], or the mediated drug delivery multi-rotor [16] capable of giving a subcutaneous injection.

This paper presents the results from a users' survey conducted over 18 participants (11 men and 7 women) to evaluate the performance of a fully-actuated multi-rotor platform equipped with a front basket intended to conduct the fast delivery of medicines directly to the user's home through the window. This study takes into account the close interaction involved during the aerial handover, paying particular attention to human-centered aspects in order to make the operation safe, fast, and comfortable. This study is based on our previous works in aerial delivery (handover) with multi-rotors [17][18]. In particular, the proposed solution for through-window home aerial delivery is introduced in [18].

The rest of the paper is organized as follows. Section 2 describes the intended application. Section 3 presents the aerial platform. Section 4 describes the methodology for evaluating the aerial delivery system, including the questionnaire and the scenario used for the tests, reporting the results from the users in Section 5. Finally, the conclusions are summarized in Section 6.

2. INTENDED APPLICATION

The situation of confinement that occurred in 2020 evidenced the necessity for counting with some way for delivering medicines, sample tests, food and other goods to people isolated in their houses, overcoming extreme situations like this pandemic that affected to millions of citizens. Strict restrictions or limitations in the mobility of the people due to health reasons, particularly to elderly, motivate the development and application of aerial robots capable to deliver light parcels like medicines directly to the users' home, taking into account that most urban environments have hundreds or thousands of multi-story apartment buildings. Although wheeled-legged robots have developed advanced locomotion capabilities in recent years [19][20], the access to the interior of buildings remains challenging since it requires opening the door, climbing stairs or taking the elevator, with a wide variety of possible conditions in this kind of environments. Aerial robots simplify significantly the problem of reaching the home of the users when its interior can be accessed by flying in front of the facade of the building. The window of the user's home is taken here as the interface and reference frame for the delivery operation. The user simply has to open the window and stretch the arm to grasp the parcel carried by the drone when this is closed enough. The concept is illustrated in Figure 1.

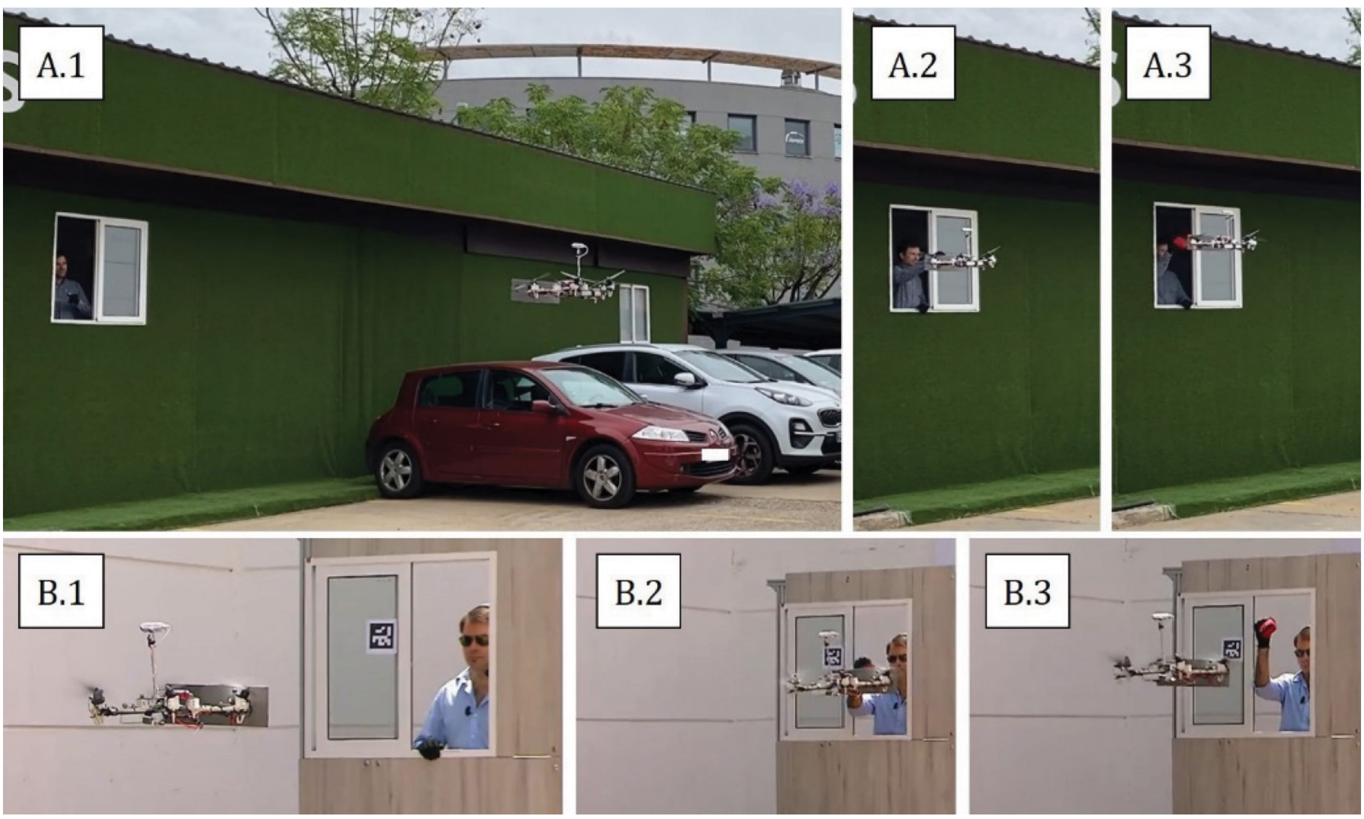

Figure 1 Through-window home aerial delivery multi-rotor. Experimental evaluation in two outdoor scenarios. Fully-actuated multi-rotor approaching to the window (A1/B1), user retrieving the parcel (A2/B2), parcel retrieved by user (A3/B3).

This paper is not focused on technological or regulatory aspects dealing with the requirements for flying aerial robots autonomously and reliably within urban environment. Instead, the paper collects the opinion and perspective of a group of users regarding the possible application and the preliminary evaluation of an aerial robot capable of delivering light parcels directly at their home. The users' survey presented here is derived from the through-window home aerial delivery system proposed and evaluated in our previous work [18] and briefly presented in next section. Whereas in most works on parcel delivery with drones the parcel is simply dropped on the ground, the through-window delivery system considers the aerial handover with the human user or with a robot manipulator [18]. Although nowadays the people is used to see drones in the media, the generalized lack of experience in the direct and close interaction with drones requires particular attention due to safety issues. Therefore, this study aims at gathering the opinion and experience from different users in a controlled environment as preliminary steps before the possible development of a through-window home aerial delivery robot operating outdoors.

3. SYSTEM DESCRIPTION

The platform developed for the through-window home aerial delivery tests in the indoor scenario is shown in Figure 2. It consists of a fully-actuated multi-rotor based on the DJI F550 hexacopter frame, widely used as research platform. Unlike conventional coplanar multi-rotors, whose translational motion requires rolling or pitching, the proposed human-centered design approach requires that the aerial robot approaches to the user maintaining constant its attitude, avoiding undesired and uncomfortable pitching motions that tend to difficult the capture of the parcel while the platform is moving or maintaining its position. This motivated the adoption in this work of the fully-actuated configuration [21][22], which decouples position and attitude control thanks to the 6-DOF (degrees of freedom) actuation provided by the tilted propellers. Note however that the maximum tilting angle in roll or pitch is limited (in this platform to ±15 degrees) due to the loss of vertical thrust and limited thrust capacity of the propellers. In any case, this platform can be controlled in fully-actuated mode or as a standard coplanar mode, increasing the range of wrench generation.

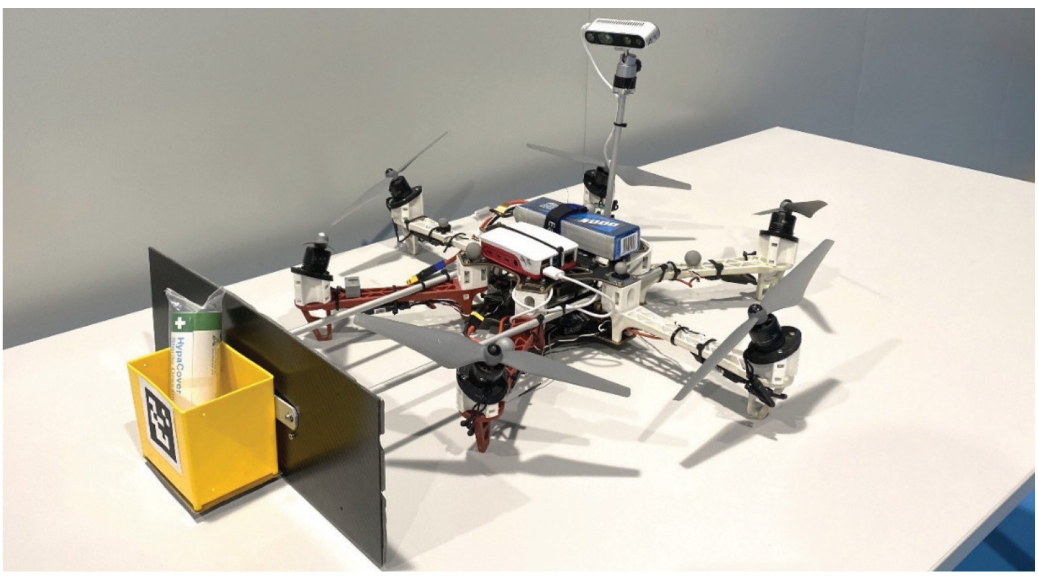

Figure 2 Prototype of fully-actuated aerial parcel delivery multi-rotor with front basket attached to the carbon fiber protection panel, and a Intel RealSense D435i camera for visual recognition of users.

The aerial robotic platform incorporates the following on-board components:

- The delivery basket, a plastic box with the top opening, attached to the multi-rotor front panel to carry the parcel.
- The carbon fiber front panel (40x15cm) supported by a pair of rods attached to the multi-rotor base, used to protect the customer from the propellers during the aerial handover operation.
- Six 3D printed plastic frames that connect the brushless motors with the multi-rotor frame with a certain tilting angle, as described in [18], to achieve the fully-actuated configuration.
- A Raspberry Pi 3 with the Navio2 autopilot running ArduPilot flight control software.
- An Intel RealSense D435i camera to be used for relative positioning with respect to the window frame using AruCo markers or other visual features, as well as for the detection of the customer.

As detailed in [18], the platform is able to carry up to 120 grams load in the basket, located at 50 cm from the center of the multi-rotor base. Higher loads exert excessive moment imbalance due to gravity that cannot be compensated by the propellers. The multi-rotor LiPo battery (4S, 4500 mA) is conveniently placed to keep the overall center of mass as much aligned as possible.

Experimental results presented in [1] evidence that the aerial platform, controlled in position with the basic cascade controller (position-velocity-attitude-angular rate), suffers significant position deviations in the X-axis when the parcel is loaded/unloaded due to the sudden change in the mass distribution. The parcel delivery case, involving parcel unload, is more favourable for the user since the platform moves away when the payload is removed. In any case, it is possible to implement control methods that compensate actively this kind of perturbations [21][22].

4. EVALUATION METHODOLOGY

The aerial delivery system is evaluated by a set of participants playing the role of users receiving a small parcel through the window of the indoor mockup scenario, considering the medicine delivery as illustrative application. The experiment, carried out individually and independently for each user, consists of three phases. First, the purpose and procedure of the experiment is explained to users. Second, the supervisor of the experiment drives the user to the mockup scenario, behind the window, representing the interior of the user's home, as shown in Figure 3. Users are encouraged to use the retrieval stick to facilitate the grasping and for safety reasons. Then, the aerial robot, initially landed at 3-4 meters from the window, takes-off carrying the parcel, approaches the window, and the user retrieves the load when he or she considers it appropriate.

Figure 3 Evaluation scenario with the mock-up of a window within the GRVC Robotics Lab indoor testbed.

After the experiment, participants fill a questionnaire. The first fourteen rating questions are rated on a scale from 0 to 5, where 0 means "very low'" and 5 is interpreted as "very high'". Additionally, two open-ended questions are formulated to gather their opinion about the aerial parcel delivery service. The sixteen questions are grouped into four categories:

- User's perception and previous knowledge on aerial robots and unmanned aerial vehicles (UAVs) in general (Q1 to Q3). These questions are focused in understanding the participant's familiarity with drone technology and their overall attitude towards drones as a beneficial technology.
  - Q1: Do you have some previous experience with UAVs?
  - Q2: Do you perceive UAVs as a beneficial technology?
  - Q3: Do you usually receive lightweight parcels at home?

- Comfort, safety and other factors involved in the realization of the experiment (Q4 to Q9). This group of questions is intended to evaluate the performance of the aerial robot described in Section 3 following the experimental procedure described before:
  - Q4: Did you feel comfortable and safe during the delivery?
  - Q5: Did you find the UAV dangerous when it was flying close to you?
  - Q6: Was it easy for you to retrieve the parcel?
  - Q7: Did you find the stick for retrieving the parcel useful?
  - Q8: Was the noise of the drone annoying for you?
  - Q9: Did you find the aerial delivery task was fast enough?
- Considerations on possible application and improvements (Q10 to Q14). These questions aim to identify participant's opinion on possible improvements for the system's design and potential future implications of the aerial delivery system:
  - Q10: Is it necessary to reduce the size of the UAV?
  - Q11: Is the proposed application useful to people?
  - Q12: Do you think aerial delivery is risky in cities due to possible failures or accidents?
  - Q13: Would you be concerned about data privacy if an UAV needs to record data (video, audio) during operation?
  - Q14: Do you think UAVs contribute to reduce CO2?
- Open-ended questions (Q15 to Q16). The last two questions focus on identifying the participant's preferences

Additionally, participants are requested to provide their age and gender in the questionnaire. This information, treated anonymously, is collected to analyze potential correlations between user demographics and their responses, enhancing the study's depth and insights. The total time devoted to the three phases of the tests is less than 10 minutes per participant.

Safety aspects were carefully considered before the realization of the tests involving the participants. The stability of the aerial platform was thoroughly evaluated by exerting different perturbations at the basket, including pushing and pulling forces, moments, and force peaks [18]. The stability of the decoupled cascade controller can be seen in the video [23]. The mockup of the window scenario provides a physical barrier that protects the user from possible collisions of the multi-rotor. The carbon fiber protection panel, although it only covers the front part of the aerial platform due to the need to reduce the overall weight, is sufficient for this purpose since the multi-rotor will move forwards or backwards facing the user, so he/she will not be exposed to the propellers. Additionally, users can use a simple stick (30 cm long) with a hook at the tip to facilitate the retrieval of the parcel by a handle, removing the risk of impact on the hand.

5. RESULTS

The experimental campaign comprised a total of 18 participants, comprising 11 men and 7 women. Since age may be considered as sensitive or personal information, four representative ranges of age were defined to be indicated by users: 18 - 29 (range A, mainly bachelor students, 10 users), 30 - 44 (range B, 3 users), 45 - 59 (range C, 4 users), and 60 or more (range D, 1 user). Intentionally, efforts were undertaken to encompass individuals with disparate levels of proficiency in aerial robotics, from no experience at all with drones (beyond their knowledge from the media), to experienced researchers in this area, thereby ensuring a heterogeneous participant pool with distinct backgrounds and varying degrees of familiarity with drone technology. The results of the rated questions are presented in Table I. In addition, Figure 4 presents the results segmented by age range and Figure 5 segmented by level of expertise. Based on the score obtained in Question 1, three level of expertise where considered in Figure 5: high level of expertise (score 4-5, 6 users), medium level of expertise (score 2-3, 7 users) and low level of expertise (score 0-1, 5 users).

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14
Avg.	2.7	4.6	3.7	4.4	1.8	4.7	4.3	2.1	4.7	2.0	4.7	2.8	2.2	4.4
Std.	1.7	0.5	1.1	0.9	1.6	0.6	1.2	1.6	0.7	1.4	0.6	0.9	1.7	0.8

Table 1. Average-standard deviation of the rating questions of Section 4, provided by the participants at the end of the tests.

Analysing the results by age in Figure 4, a similar response of each age range is observed across all questions except for Questions 8 and 13. In Question 8, it is observed that younger participants (Range A and B) do not find the noise generated by the propellers irritating, unlike the older participants (Range C and D), who do find it annoying. Similarly, in Question 13, it is evident that the younger participants are less concerned about data privacy compared to the older ones.

Similarly, analysing the results by level of expertise in Figure 5, a similar response of each age range is also observed across all questions except for Questions 5 and 13. For more experienced users, the level of danger associated with the drone flying was higher than for amateur users, as shown in Question 5. This may be attributed to their greater awareness of the potential risks of UAVs due to their higher level of expertise compared to amateur users. Additionally, expert users are more concerned about data privacy than amateur users, as shown in Question 13.

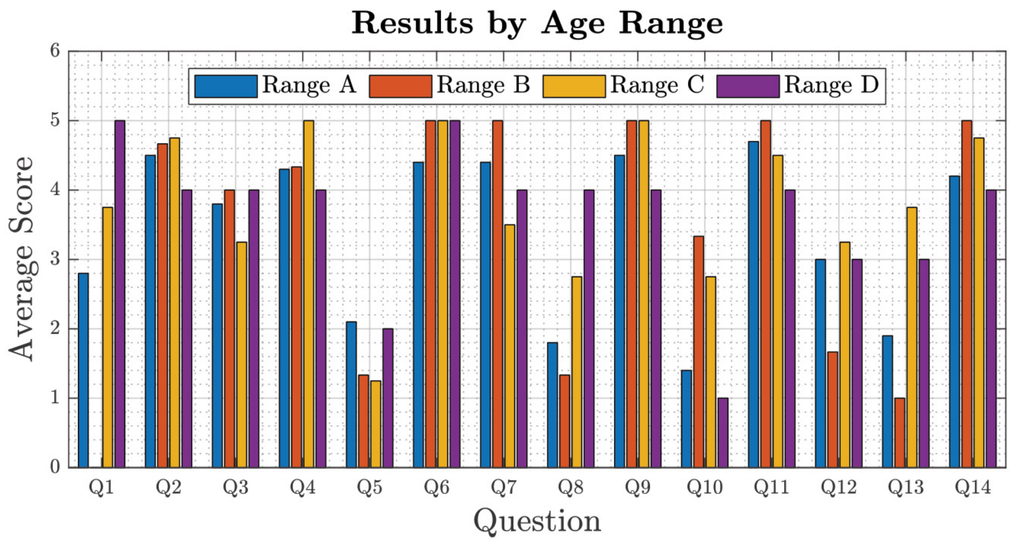

Figure 4 Average score obtained per question and segmented by age range. The four age range are: 18-29 (Range A, 10 users), 30-44 (Range B, 3 users), 45-59 (Range C, 4 users), and 60 or more (Range D, 1 user).

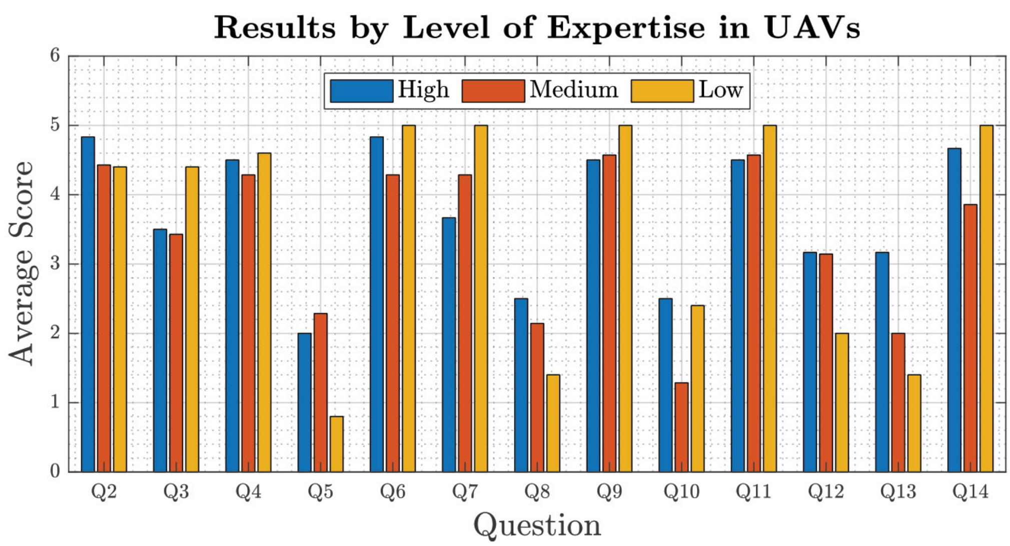

Figure 5 Average score obtained per question and segmented by level of expertise. The three levels of expertise are: High (6 users), Medium (7 users), and Low (5 users). Question 1 is not included as it identifies the level of expertise.

Some general conclusions were derived from the comparison of the responses provided by participants to the rated questions:

- Users felt safe and comfortable during the realization of the experiment. They also found the retrieval operation fast and easy, and the stick handy. Few of them felt the noise of the propellers as annoying.
- Surprisingly, users do not perceive flying robots in urban environment as risky, or do not consider this as a possibility, but they assume that drones will be reliable. Reducing the size of the drone was not considered as an issue either.
- Participants in the range of age C-D tend to be more concerned about data privacy than young users in case the aerial robot has to record audio/video during the delivery operation.
- All users agree that the intended operation can be useful to the people, and believe drones are a beneficial technology that also contribute to reduce the greenhouse emissions when compared to vehicles employed nowadays for parcel delivery.

Regarding the open questions, users list as possible items to be delivered by this aerial service: pharmacy products, food, clothes, or consumer electronics products. More generally, users make reference to products that are received from popular delivery companies, ordered online. Also parcels that are small and lightweight, thus easy to retrieve, and not very expensive. The responses to the question about which would be a reasonable cost for the aerial delivery service is diverse. A number of users did not have a clear response. Several related this possible cost with other services like subscription to digital channels for video streaming. Some participants suggested a monthly cost between 3 and 20 euros, stating in several cases that should depend on the particular service provided to the users.

6. CONCLUSIONS

This paper presented the results of a users' survey involving 18 participants evaluating several aspects of a through-window home aerial delivery robot consisting of a fully-actuated multi-rotor equipped with a front basket for carrying light parcels (less than 120 grams), like medicines. The tests were conducted in an indoor flight testbed with a mockup scenario of the window. The responses from the users show that all of them agree on the high speed of the aerial delivery service (taking into account that the tests were conducted in a limited flight volume), the simplicity of use, and on its usefulness for the considered medicine delivery application. Users did not perceive danger in the proximity of the drone during the operation, which may be indicative of the lack of knowledge about the damage that the propellers of certain size can cause upon impact, raising some concerns in this regard. The fully-actuated configuration was proven to be a suitable rotor arrangement as the horizontal approaching motion allowed users to retrieve the parcel comfortably.

As future work, the development of home delivery multi-rotors for light payloads in urban environments should be focused on reducing the overall weight of the platform in order to reduce the risk of damage in case of impact or crash (worst-case scenario). This constraints the weight of the on-board sensors required for autonomous navigation outdoors, which is both a design and technological aspect. Handling wind is also another relevant aspect, related to the ability of the fully-actuated multi-rotor for generating forces in the horizontal plan. Finally, the adaptation of the pharmacies is considered to be relevant, so these aerial robots can be autonomously loaded with the medicine and deployed quickly for fast service.

ACKNOWLEDGEMENTS

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2025 INTERNATIONAL CONFERENCE ON UNMANNED AIRCRAFT SYSTEMS (ICUAS '25)

May 14 - 17, 2025
Charlotte, NC, USA
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The 2025 International Conference on Unmanned Aircraft Systems, **ICUAS '25**, will take place on May 14-17. It is organized in Charlotte, NC, the second-largest banking center in the United States. **ICUAS '25** is sponsored by the University of North Carolina at Charlotte (UNC Charlotte), and the conference venue is on the campus facilities of the University. Charlotte is easily accessible via the Charlotte Douglas International Airport. The city offers many attractions including the Sullenberger Aviation Museum, U.S. National Whitewater Center, Carowinds Amusement Park, the Charlotte Motor Speedway, and other cultural amenities and entertainment sites.

ICUAS '25 centers around civil and public domain applications, and on the impact of unmanned aviation to society. Technical challenges cover a wide spectrum of topics; however, emphasis is given to 1) **real-time aerial manipulation**; 2) **multi-mode platforms**; 3) **design for resiliency and autonomy**, 4) **human factors and ethical AI as applied to unmanned aviation**, 5) **learning-based navigation and control**, and 6) **regulations for integration into the national airspace**.

ICUAS '25 brings together, under one forum, national and international organizations, federal agencies, industry, private sector, authorities, end-users, and practitioners, working towards defining roadmaps of UAS, setting expectations, technical requirements and standards that are prerequisite to their full utilization and integration into the national airspace. Special emphasis is given to research opportunities, and to '*what comes next*' in terms of tools and support technologies that are needed to advance the state-of-the-art.

ICUAS '25 offers unique opportunities to meet, interact and shape the future of unmanned aviation, worldwide, bringing together technical, regulatory, and legal communities. Details and logistics about the conference may be found at http://www.uasconferences.com and related links. The conference is fully sponsored by the **ICUAS Association, Inc.**, a non-profit organization, see www.icuas.com. It is technically cosponsored by the IEEE Control Systems Society, the IEEE Robotics and Automation Society, and the Mediterranean Control Association.

Part of **ICUAS '25** is the **UAV Competition.** The Competition is student-focused and student-centered, offering unique opportunities for students to test and compare their skills with those of their peers worldwide. The competition is organized in two stages: simulation qualifiers and in-person finals. The finals will take place during the conference, allowing students to meet and participate in the conference, too. Details on how to participate in the UAV Competition are available on the conference website.

CONFERENCE STRUCTURE

ICUAS '25 is a 'physical presence only' four-day event. May 14-16 spans the three-day technical conference. May 17 is devoted to Workshops and Tutorials.

IMPORTANT DUE DATES

February 4, 2025:	Full Papers / Invited Sessions / Tutorial Proposals Due
February 10, 2025:	UAV Competition: simulation-based scenario
March 25, 2025:	Acceptance / Rejection Notification
March 25 – April 10, 2025:	Early Registration and Upload Final, Camera Ready Papers

SUBMISSIONS

Papers: Paper format (two-column) follows IEEE guidelines. Electronic submission will be handled through PaperCept - details are available on the conference web site. Submitted papers should be classified as *Contributed* or *Invited Session* (max. 8 pages), or *Poster* (max. 6 pages) papers. Accepted, contributed, and invited session papers only will be allowed up to two additional pages for an extra charge per additional page. Poster papers should aim at novel and cutting-edge ideas with potential, however, not yet fully developed.

Invited Sessions: Proposals for invited sessions should contain a summary statement describing the motivation and relevance of the proposed session, the invited paper titles, and the names of the authors. Authors must submit FULL invited papers. Each paper must be marked as "Invited Session Paper".

Workshops and Tutorials: Proposals for workshops and tutorials should contain title, list of speakers, and extended summaries (2000 words) of their presentations.

All contributions (papers, invited papers, proposals for invited sessions, workshops, and tutorials) must be submitted electronically through https://controls.papercept.net by the due date.

Paper Review Process: All submitted papers will undergo a thorough peer review process coordinated by the Program Chairs, Advisory Committee Members, IPC members, Associate Editors, and qualified reviewers. Each paper will be reviewed by (at least) three qualified reviewers. Each Associate Editor will make recommendations. The Program Chairs will finalize and announce decisions by the due date. Each submitted paper will be checked for originality through the iThenticate Plagiarism Detection Software.

The application to receive IEEE CSS and RAS Technical Co-Sponsorship has been submitted.