1. **Title:** Autonomous Space Debris Cleanup System
2. **Prior-Art**
3. Published Patents and Patent Applications

- **US Patent No. 8,813,512 B2**
  - **Title:** "Method and System for Space Debris Removal"
  - **Assignee:** Raytheon Company
  - **Summary:** This patent describes a method and system for removing space debris using a spacecraft equipped with a net or tether system. The spacecraft captures debris and either deorbits it or transfers it to a safe disposal orbit.
  - **Distinguishing Aspects:** Our Autonomous Space Debris Cleanup System (ASDCS) utilizes multiple capture mechanisms (robotic arms, nets, and harpoons) and integrates a comprehensive sensor suite for precise debris detection and classification. Unlike the method described in this patent, ASDCS employs AI-driven autonomous operation, minimizing human intervention.
- **US Patent No. 9,546,822 B2**
  - **Title:** "Spacecraft for Capturing and Removing Space Debris"
  - **Assignee:** Northrop Grumman Corporation
  - **Summary:** This patent details a spacecraft designed to capture and remove space debris using robotic arms and a collection bag. The system can deorbit the captured debris or store it for later removal.
  - **Distinguishing Aspects:** ASDCS differs by incorporating AI algorithms that enable real-time decision-making and continuous learning. Additionally, our

system integrates radar, lidar, optical cameras, and infrared sensors, providing robust and reliable debris detection capabilities. The combination of AI and diverse capture mechanisms enhances operational efficiency and flexibility.

- **US Patent No. 10,364,092 B2**
  - **Title:** "Autonomous Satellite for Space Debris Capture and Removal"
  - **Assignee:** Lockheed Martin Corporation
  - **Summary:** This patent describes an autonomous satellite equipped with robotic arms and thrusters for capturing and removing space debris. The satellite uses sensors to detect debris and adjusts its trajectory to capture the debris.
  - **Distinguishing Aspects:** Our ASDCS goes beyond by integrating a comprehensive energy management system with solar panels and high-capacity batteries, ensuring continuous operation during extended missions. The system's AI-driven autonomy and multiple capture mechanisms provide superior adaptability and effectiveness in various debris scenarios.

4. Non-Patent Literature
5. **Article: "Active Debris Removal: Technologies and Challenges"**
   - **Source:** Advances in Space Research, 2020
   - **Summary:** This article reviews current technologies and challenges associated with active debris removal, including the use of nets, robotic arms, and harpoons. It highlights the need for autonomous systems and the integration of advanced sensors for effective debris management.

- **Relevance:** The article underscores the significance of our ASDCS's AI-driven autonomy and multi-sensor integration. The system's ability to operate autonomously and adapt to different debris types addresses the challenges discussed in the article.

6. **Conference Presentation: "Innovations in Space Debris Mitigation"**
   - **Event:** International Astronautical Congress, 2021
   - **Summary:** The presentation covers recent innovations in space debris mitigation, focusing on the use of AI and machine learning for debris detection and classification. It emphasizes the importance of real-time data processing and autonomous decision-making.
   - **Relevance:** The ASDCS aligns with these innovations by employing advanced AI algorithms for real-time debris detection, classification, and autonomous operation. The system's continuous learning capability enhances its effectiveness over time.
7. **Book: "Orbital Debris: A Technical Assessment"**
   - **Author:** National Research Council
   - **Summary:** This book provides a comprehensive assessment of the orbital debris problem, discussing various mitigation strategies and technologies. It highlights the need for robust detection systems and effective capture mechanisms.
   - **Relevance:** The ASDCS's multi-sensor suite and versatile capture mechanisms directly address the technical requirements outlined in the book. The integration of radar, lidar, optical cameras, and infrared sensors ensures accurate debris

detection, while the robotic arms, nets, and harpoons provide flexible capture solutions.

8. Public Use or Sale

- **ESA's ClearSpace-1 Mission**
    - **Summary:** The European Space Agency's ClearSpace-1 mission aims to remove a piece of space debris using a spacecraft equipped with robotic arms. The mission targets the Vespa payload adapter left in orbit by a previous mission.
    - **Distinguishing Aspects:** While ClearSpace-1 utilizes robotic arms, the ASDCS offers additional capture mechanisms and integrates AI-driven autonomous operation, providing enhanced adaptability and efficiency in debris removal.
- **Astroscale's ELSA-d Mission**
    - **Summary:** Astroscale's End-of-Life Services by Astroscale-demonstration (ELSA-d) satellite captures and deorbits defunct satellites using a magnetic capture mechanism. The mission demonstrated successful capture of simulated debris in orbit.
    - **Distinguishing Aspects:** Unlike ELSA-d, the ASDCS employs multiple capture mechanisms and advanced sensors for comprehensive debris detection and classification. The AI-driven autonomous operation further distinguishes our system by enabling real-time decision-making and continuous adaptation.

9. Prior Public Disclosure

- **Lecture: "Advancements in Space Debris Management"**

  - **Speaker:** Dr. Emily Green, MIT
  - **Summary:** This lecture discusses recent advancements in space debris management, including the use of AI and robotics. It highlights the importance of autonomous systems and the integration of advanced sensors.
  - **Relevance:** The ASDCS aligns with the advancements discussed in the lecture, employing AI algorithms for autonomous operation and integrating a multi-sensor suite for precise debris detection and classification.
- **Trade Show: "Space Tech Expo 2022"**
  - **Exhibit:** Various exhibitors showcased technologies for space debris mitigation, including autonomous capture systems and advanced sensor integration.
  - **Relevance:** The ASDCS's combination of AI-driven autonomy, versatile capture mechanisms, and comprehensive sensor integration positions it as a leading solution in the space debris management market.

10. Overcoming Prior Art
11. The prior art review reveals several existing technologies and methods for space debris removal. However, the Autonomous Space Debris Cleanup System (ASDCS) offers significant advancements and unique features that distinguish it from existing solutions. The key differentiators include:

- **AI-Driven Autonomy:**
  - The ASDCS employs advanced AI algorithms for real-time decision-making, continuous learning, and autonomous operation. This reduces the need for human intervention and enhances operational efficiency.

- **Comprehensive Sensor Suite:**
    - The integration of radar, lidar, optical cameras, and infrared sensors provides robust and reliable debris detection and tracking. This multi-sensor approach ensures accurate classification and enhances the system's adaptability to various debris scenarios.
- **Versatile Capture Mechanisms:**
    - The ASDCS utilizes multiple capture mechanisms, including robotic arms, nets, and harpoons, allowing it to handle debris of different sizes and shapes. This versatility improves the system's effectiveness and operational flexibility.
- **Energy Management System:**
    - The system incorporates advanced solar panels and high-capacity batteries, ensuring continuous operation during extended missions. The AI optimizes energy usage, balancing power allocation to critical components.
- **Compliance and Safety:**
    - The ASDCS adheres to international space regulations and guidelines, ensuring safe and responsible operations. The AI continuously monitors compliance and adjusts operations to prevent collisions and minimize risks.

12. Conclusion
13. The Autonomous Space Debris Cleanup System represents a significant advancement in space debris management technology. By addressing the limitations of existing solutions and incorporating cutting-edge AI, sensor integration, and versatile capture mechanisms, the ASDCS offers a robust and effective solution for mitigating the risks posed by space

debris. This thorough prior art review confirms the novelty and non-obviousness of the ASDCS, supporting its patentability and market potential.

14. **Technical Field**

15. This invention relates to space technologies, specifically to an autonomous system designed for the detection, capture, and removal of space debris from Earth's orbit.

16. **Background of the Invention**

17. Space debris, including defunct satellites, spent rocket stages, and fragments from collisions and disintegration events, poses a significant threat to operational satellites, spacecraft, and the International Space Station (ISS). Current methods of debris removal are limited and often require costly and complex missions. There is a need for an autonomous, efficient, and cost-effective system to address the growing problem of space debris.

18. **Summary of the Invention**

19. The present invention is an autonomous space debris cleanup system designed to detect, capture, and remove space debris from Earth's orbit. The system employs advanced sensors, AI for debris detection and tracking, and robotic mechanisms for debris capture and disposal. This innovation aims to enhance the safety of space operations by effectively managing space debris.

20. Brief Description of the Drawings

21. **Fig. 1: Overview of the Autonomous Space Debris Cleanup System**

22. This figure provides an overview of the Autonomous Space Debris Cleanup System, highlighting its main components and their interconnections.

23. Explanation of Each Element and Connections

- **Central Control Unit (CCU) (101):**
    - The CCU is the system's brain, responsible for coordinating all operations, including processing data from sensors, executing AI algorithms, and controlling capture mechanisms.
    - **Connections:**
    - Solid lines to all sensors, indicating direct data input.
    - Solid lines to all capture mechanisms, indicating control signals.
    - Bi-directional line to the Energy Management System, indicating energy flow and management.
- **Radar Sensor (102):**
    - Provides long-range detection of space debris using radio waves.
    - **Connection:** Solid line to the CCU, indicating data transfer for debris detection.
- **Lidar Sensor (103):**
    - Uses laser pulses to measure distances and create precise 3D maps of debris.
    - **Connection:** Solid line to the CCU, indicating data transfer for debris mapping.
- **Optical Camera (104):**
    - Captures visual images of space debris, aiding in identification and tracking.
    - **Connection:** Solid line to the CCU, indicating image data transfer.
- **Infrared Sensor (105):**

  - Detects heat signatures of space debris, useful in low-visibility conditions.
  - **Connection:** Solid line to the CCU, indicating infrared data transfer.
- **AI Algorithms Unit (106):**
  - Processes data from sensors to identify, classify, and track space debris using advanced AI algorithms.
  - **Connection:** Solid line with an arrow to the CCU, indicating data processing output.
- **Robotic Arms (107):**
  - Provides precise control for capturing small to medium-sized debris.
  - **Connection:** Solid line to the CCU, indicating control signals for operation.
- **Nets (108):**
  - Captures larger or irregularly shaped debris using flexible netting.
  - **Connection:** Solid line to the CCU, indicating control signals for deployment.
- **Harpoons (109):**
  - Secures large or fast-moving debris using projectile-based capture.
  - **Connection:** Solid line to the CCU, indicating control signals for activation.
- **Energy Management System (110):**
  - Optimizes energy use across the system, ensuring continuous operation.
  - **Connection:** Bi-directional line to the CCU, indicating energy flow and management.

- **Debris Disposal System (111):**
    - Handles the disposal of captured debris, either by deorbiting it or transporting it to a designated graveyard orbit.
    - **Connection:** Solid line with an arrow from the CCU, indicating disposal commands.

24. **Fig. 2: Debris Detection Process**
25. This figure illustrates the debris detection process, detailing the steps from initial sensor data acquisition to AI-driven debris identification and classification.
26. Explanation of Each Element and Connections

- **Initial Sensor Data Acquisition (201):**
    - This step involves collecting raw data from various sensors (radar, lidar, optical, and infrared).
    - **Connections:**
    - Solid lines to Radar Data Processing, Lidar Data Processing, Optical Data Processing, and Infrared Data Processing, indicating the flow of raw data.
- **Radar Data Processing (202):**
    - Processes radar data to detect and track space debris using radio waves.
    - **Connection:** Solid line from Initial Sensor Data Acquisition, indicating the receipt of raw radar data.
- **Lidar Data Processing (203):**
    - Analyzes lidar data to create precise 3D maps of detected debris.
    - **Connection:** Solid line from Initial Sensor Data Acquisition, indicating the receipt of raw lidar data.

- **Optical Data Processing (204):**
    - Processes visual data from optical cameras to assist in identifying and tracking debris.
    - **Connection:** Solid line from Initial Sensor Data Acquisition, indicating the receipt of raw optical data.
- **Infrared Data Processing (205):**
    - Analyzes infrared data to detect heat signatures of space debris.
    - **Connection:** Solid line from Initial Sensor Data Acquisition, indicating the receipt of raw infrared data.
- **Data Fusion and Analysis (206):**
    - Combines data from radar, lidar, optical, and infrared sensors to create a comprehensive understanding of the debris environment.
    - **Connections:**
    - Solid lines from Radar Data Processing, Lidar Data Processing, Optical Data Processing, and Infrared Data Processing, indicating the integration of processed data.
- **Debris Identification and Classification (207):**
    - Uses AI algorithms to identify and classify debris based on size, trajectory, and risk level.
    - **Connection:** Solid line from Data Fusion and Analysis, indicating the flow of fused data for identification and classification.

27. **Fig. 3: Autonomous Navigation System**

28. This figure illustrates the autonomous navigation system, detailing the steps from initial path planning to navigation execution, including collision detection and obstacle avoidance.

29. Explanation of Each Element and Connections

- **Initial Path Planning (301):**
    - This step involves calculating the initial trajectory for the spacecraft to reach the target debris.
    - **Connection:** Solid lines to Collision Detection and Path Adjustment, indicating the initial planning phase.
- **Collision Detection (302):**
    - Uses sensor data to detect potential collisions with other space objects.
    - **Connection:** Solid line from Initial Path Planning, indicating the receipt of initial path data.
- **Path Adjustment (303):**
    - Adjusts the planned path based on collision detection data to avoid obstacles.
    - **Connection:** Solid line from Initial Path Planning, indicating the receipt of initial path data.
- **Real-Time Data Monitoring (304):**
    - Continuously monitors sensor data for any changes in the environment that may require path adjustments.
    - **Connection:** Solid line from Collision Detection, indicating the monitoring of potential collisions.

- **Obstacle Avoidance (305):**
    - Implements avoidance maneuvers based on real-time data to steer clear of obstacles.
    - **Connection:** Solid line from Path Adjustment, indicating the adjustment process for avoiding obstacles.
- **Trajectory Optimization (306):**
    - Optimizes the trajectory based on real-time data to ensure efficient navigation to the target.
    - **Connections:** Solid lines from Real-Time Data Monitoring and Obstacle Avoidance, indicating the integration of monitored and adjusted data.
- **Navigation Execution (307):**
    - Executes the optimized navigation path, guiding the spacecraft to the target debris.
    - **Connection:** Solid line from Trajectory Optimization, indicating the execution phase of the optimized path.

30. **Fig. 4: Deployment of Capture Mechanisms**
31. This figure illustrates the deployment process of the various capture mechanisms (robotic arms, nets, and harpoons) based on the characteristics of detected debris, including the confirmation of debris capture.
32. Explanation of Each Element and Connections

- **Debris Detection Confirmation (401):**
    - Confirms the presence and characteristics of the detected debris using sensor data.

- **Connection:** Solid line to Capture Mechanism Selection, indicating the transfer of confirmed debris data.

- **Capture Mechanism Selection (402):**
  - Selects the most suitable capture mechanism based on the characteristics of the debris.
  - **Connection:** Solid line from Debris Detection Confirmation, indicating the decision process for selecting the capture mechanism.
- **Robotic Arms Deployment (403):**
  - Deploys robotic arms for precise capture of small to medium-sized debris.
  - **Connection:** Solid line from Capture Mechanism Selection, indicating the deployment of robotic arms.
- **Nets Deployment (404):**
  - Deploys nets for capturing larger or irregularly shaped debris.
  - **Connection:** Solid line from Capture Mechanism Selection, indicating the deployment of nets.
- **Harpoons Deployment (405):**
  - Deploys harpoons for securing large or fast-moving debris.
  - **Connection:** Solid line from Capture Mechanism Selection, indicating the deployment of harpoons.
- **Capture Mechanism Operation (406):**
  - Executes the capture operation using the selected mechanism to secure the debris.

  - **Connections:** Solid lines from Robotic Arms Deployment, Nets Deployment, and Harpoons Deployment, indicating the operation of the selected mechanism.
- **Debris Secured Confirmation (407):**
  - Confirms that the debris has been successfully captured and secured.
  - **Connection:** Solid line from Capture Mechanism Operation, indicating the confirmation of secured debris.

33. **Fig. 5: Energy Management System**
34. This figure illustrates the energy management system, detailing the steps from energy harvesting to distribution and optimization, including monitoring and supplying power to critical systems.
35. Explanation of Each Element and Connections

- **Solar Panel Array (501):**
  - Collects solar energy from the sun to power the system.
  - **Connection:** Solid line to Energy Harvesting Unit, indicating the transfer of collected solar energy.
- **Energy Harvesting Unit (502):**
  - Converts solar energy into electrical power for storage and usage.
  - **Connection:** Solid line from Solar Panel Array, indicating the energy harvesting process.
- **Energy Storage System (503):**
  - Stores the harvested energy in high-capacity batteries for continuous operation.

  - **Connection:** Solid line from Energy Harvesting Unit, indicating the storage of harvested energy.
- **Power Distribution Unit (504):**
  - Distributes stored energy to various non-critical systems within the spacecraft.
  - **Connection:** Solid line from Energy Storage System, indicating the distribution of stored energy.
- **Critical Systems Power Supply (505):**
  - Provides dedicated power supply to critical systems ensuring their continuous operation.
  - **Connection:** Solid line from Energy Storage System, indicating the allocation of energy to critical systems.
- **Energy Usage Monitoring (506):**
  - Monitors the energy consumption of all system components in real-time.
  - **Connections:** Solid lines from Power Distribution Unit and Critical Systems Power Supply, indicating the monitoring of energy usage.
- **Energy Optimization Algorithms (507):**
  - Uses AI algorithms to optimize energy usage across all components, ensuring efficient power management.
  - **Connection:** Solid line from Energy Usage Monitoring, indicating the optimization of monitored energy usage.

36. **Fig. 6: Debris Disposal Process**

37. This figure illustrates the debris disposal process, detailing the steps from debris secured confirmation to disposal, including deorbiting and transferring to a graveyard orbit.
38. Explanation of Each Element and Connections

- **Debris Secured Confirmation (601):**
    - Confirms that the debris has been successfully captured and secured.
    - **Connection:** Solid line to Disposal Method Selection, indicating the transition from capture to disposal.
- **Disposal Method Selection (602):**
    - Determines the most appropriate method for disposing of the secured debris.
    - **Connection:** Solid line from Debris Secured Confirmation, indicating the selection process for disposal method.
- **Deorbiting Process (603):**
    - Initiates the process of lowering the debris' orbit to ensure it burns up in the Earth's atmosphere.
    - **Connection:** Solid line from Disposal Method Selection, indicating the chosen method for disposal.
- **Graveyard Orbit Transfer (604):**
    - Transfers the debris to a designated graveyard orbit, where it poses no threat to operational satellites.
    - **Connection:** Solid line from Disposal Method Selection, indicating the chosen method for disposal.
- **Controlled Descent Execution (605):**

- Executes the controlled descent of the debris, ensuring it follows the intended path for safe disposal.
- **Connections:** Solid lines from Deorbiting Process and Graveyard Orbit Transfer, indicating the execution of the selected disposal method.

- **Burn-Up Confirmation (606):**
    - Confirms that the debris has successfully burned up in the Earth's atmosphere or has been safely placed in the graveyard orbit.
    - **Connection:** Solid line from Controlled Descent Execution, indicating the final confirmation of disposal.

39. **Fig. 7: AI Algorithms Learning and Adaptation**
40. This figure illustrates the learning and adaptation process of AI algorithms, detailing the steps from initial data collection to continuous learning and real-time adaptation.
41. Explanation of Each Element and Connections

- **Initial Data Collection (701):**
    - Collects raw data from sensors and other system components to be used for training AI algorithms.
    - **Connection:** Solid line to Data Preprocessing, indicating the transfer of collected data.
- **Data Preprocessing (702):**
    - Cleans and prepares the collected data for training by removing noise and formatting it appropriately.
    - **Connection:** Solid line from Initial Data Collection, indicating the preprocessing of collected data.

- **Training Phase (703):**
  - Trains the AI algorithms using the preprocessed data to recognize patterns and make predictions.
  - **Connection:** Solid line from Data Preprocessing, indicating the use of preprocessed data for training.
- **Model Evaluation (704):**
  - Evaluates the performance of the trained AI models using validation data to assess their accuracy.
  - **Connection:** Solid line from Training Phase, indicating the evaluation of trained models.
- **Model Optimization (705):**
  - Optimizes the AI models to improve their performance based on the evaluation results.
  - **Connection:** Solid line from Training Phase, indicating the optimization of trained models.
- **Real-Time Adaptation (706):**
  - Adapts the AI models in real-time based on new data and changing conditions to maintain high performance.
  - **Connections:** Solid lines from Model Evaluation and Model Optimization, indicating the adaptation process based on evaluated and optimized models.
- **Continuous Learning (707):**

  - Continuously updates the AI models with new data to enhance their learning and improve their accuracy over time.
  - **Connection:** Solid line from Real-Time Adaptation, indicating the continuous learning process.

42. **Fig. 8: Safety and Compliance Protocols**
43. This figure illustrates the safety and compliance protocols, detailing the steps from the initial system check to the execution of safety protocols, including compliance verification and real-time monitoring.
44. Explanation of Each Element and Connections

- **Initial System Check (801):**
  - Conducts a comprehensive check of all system components to ensure they are functioning correctly before operations begin.
  - **Connection:** Solid line to Compliance Verification, indicating the transition from system check to compliance verification.
- **Compliance Verification (802):**
  - Verifies that the system adheres to international space regulations and guidelines.
  - **Connection:** Solid line from Initial System Check, indicating the verification process following the system check.
- **Collision Avoidance Protocol (803):**
  - Implements protocols to avoid collisions with other space objects, ensuring safe operation.

  - **Connection:** Solid line from Compliance Verification, indicating the application of verified compliance to collision avoidance.
- **Restricted Zone Monitoring (804):**
  - Monitors for any restricted zones in space to prevent the system from entering areas that are off-limits.
  - **Connection:** Solid line from Compliance Verification, indicating the monitoring of restricted zones based on compliance.
- **Real-Time Compliance Monitoring (805):**
  - Continuously monitors the system's operations to ensure ongoing compliance with safety regulations and protocols.
  - **Connections:** Solid lines from Collision Avoidance Protocol and Restricted Zone Monitoring, indicating the integration of collision avoidance and restricted zone monitoring into real-time compliance monitoring.
- **Safety Protocols Execution (806):**
  - Executes predefined safety protocols to mitigate risks and ensure the safe operation of the system.
  - **Connection:** Solid line from Real-Time Compliance Monitoring, indicating the execution of safety protocols based on real-time monitoring.

45. **Fig. 9: Ground Control Interface**
46. This figure illustrates the ground control interface, detailing the steps from system status monitoring to command input and system feedback, including the display of debris tracking data and real-time telemetry.

47. Explanation of Each Element and Connections

- **System Status Monitoring (901):**
  - Continuously monitors the overall status of the space debris cleanup system, providing real-time updates.
  - **Connection:** Solid line to Debris Tracking Data Display, indicating the flow of system status information.
- **Debris Tracking Data Display (902):**
  - Displays real-time data on the tracked debris, including position, trajectory, and size.
  - **Connection:** Solid line from System Status Monitoring, indicating the display of monitored status data.
- **Manual Override Control (903):**
  - Allows ground control to manually override the system's autonomous operations if necessary.
  - **Connection:** Solid line from Debris Tracking Data Display, indicating the option for manual control based on tracking data.
- **Real-Time Telemetry Display (904):**
  - Displays real-time telemetry data from the system, including sensor readings and operational status.
  - **Connection:** Solid line from Debris Tracking Data Display, indicating the display of telemetry data.
- **Command Input Interface (905):**

- Provides an interface for ground control to input commands and control the system's operations.
- **Connections:** Solid lines from Manual Override Control and Real-Time Telemetry Display, indicating the input of commands based on manual control and telemetry data.

- **System Feedback Display (906):**
  - Displays feedback from the system in response to commands inputted by ground control, confirming actions taken.
  - **Connection:** Solid line from Command Input Interface, indicating the display of feedback based on input commands.

48. **Fig. 10: Comprehensive Sensor Suite Integration**
49. This figure illustrates the integration of the comprehensive sensor suite with the Central Control Unit (CCU), detailing the connections between the different sensors, data fusion, and output processes.
50. Explanation of Each Element and Connections

- **Central Control Unit (CCU) (1001):**
  - Serves as the main hub for processing data from various sensors and coordinating the system's operations.
  - **Connections:**
    1. Solid lines to Radar Sensor, Lidar Sensor, Optical Camera, and Infrared Sensor, indicating direct data inputs.
    2. Solid line to Sensor Data Output, indicating the final processed data output.

- **Radar Sensor (1002):**
  - Detects and tracks space debris using radio waves.
  - **Connection:** Solid line to CCU, indicating the transfer of radar data.
- **Lidar Sensor (1003):**
  - Creates precise 3D maps of debris using laser pulses.
  - **Connection:** Solid line to CCU, indicating the transfer of lidar data.
- **Optical Camera (1004):**
  - Captures visual images of space debris for identification and tracking.
  - **Connection:** Solid line to CCU, indicating the transfer of optical data.
- **Infrared Sensor (1005):**
  - Detects heat signatures of debris, aiding in low-visibility conditions.
  - **Connection:** Solid line to CCU, indicating the transfer of infrared data.
- **Data Fusion Unit (1006):**
  - Combines data from all sensors to create a comprehensive understanding of the debris environment.
  - **Connections:**
    1. Solid lines from Radar Sensor, Lidar Sensor, Optical Camera, and Infrared Sensor, indicating the integration of sensor data.
    2. Solid line to Sensor Data Output, indicating the transfer of fused data for output.
- **Sensor Data Output (1007):**
  - Provides the final processed data from the integrated sensors for further use in debris detection and tracking.

- **Connection:** Solid line from Data Fusion Unit, indicating the output of fused sensor data.

51. **Detailed Description of the Invention**

52. The present invention relates to an autonomous system designed for the detection, capture, and removal of space debris from Earth's orbit. This system, referred to as the "Autonomous Space Debris Cleanup System," integrates advanced sensors, artificial intelligence (AI) algorithms, and robotic mechanisms to manage space debris effectively. The detailed description provided herein will enable someone skilled in the relevant field to replicate and utilize the invention.

53. System Architecture

54. The Autonomous Space Debris Cleanup System comprises several integrated components designed to detect, capture, and remove space debris. The primary components include a central control unit, multiple detection sensors, AI algorithms, and robotic capture mechanisms. The system's architecture is detailed below:

55. **Central Control Unit (CCU)**

    - The CCU serves as the brain of the system, coordinating all operations. It houses the AI algorithms responsible for real-time decision-making. The CCU processes data from the detection sensors and directs the actions of the capture mechanisms. It ensures autonomous operation, making informed decisions based on analyzed data.
    - The CCU integrates with various subsystems, ensuring seamless communication and coordination. It also manages energy allocation and system health monitoring.

56. **Detection Sensors**

- The system utilizes a combination of radar, lidar, optical cameras, and infrared sensors to detect and track space debris. These sensors provide comprehensive coverage and can identify debris of various sizes and at different altitudes.
- **Radar Sensor**: Provides long-range detection using radio waves, suitable for detecting larger debris objects.
- **Lidar Sensor**: Uses laser pulses to create precise 3D maps, useful for mapping debris in detail.
- **Optical Camera**: Captures visual images, aiding in the identification and tracking of debris.
- **Infrared Sensor**: Detects heat signatures, useful for tracking debris in low-visibility conditions.

57. **AI Algorithms**

- The AI algorithms are a critical component, enabling autonomous operation. They analyze sensor data to identify and classify debris based on size, trajectory, and risk level. The AI continuously learns and adapts from past encounters, improving detection accuracy and decision-making over time.
- The AI algorithms include machine learning models that enhance detection accuracy by learning from historical data. These models can classify debris, predict collision risks, and optimize capture strategies.

58. **Robotic Capture Mechanisms**

- The system includes multiple capture mechanisms such as robotic arms, nets, and harpoons, designed to handle debris of different sizes and shapes. These mechanisms are controlled by the AI, which determines the most appropriate capture method based on the debris characteristics.

- **Robotic Arms**: Provide precise control for capturing small to medium-sized debris.
- **Nets**: Capture larger or irregularly shaped debris using flexible netting.
- **Harpoons**: Secure large or fast-moving debris using projectile-based capture.

59. **Energy Management System**

- The energy management system ensures continuous operation during extended missions. Solar panels and energy storage units are integrated into the system, with the AI optimizing energy usage across various components. This ensures that the system remains operational even during periods without direct sunlight.
- The system includes advanced solar panels for energy harvesting and high-capacity batteries for energy storage. The AI manages power allocation to critical and non-critical systems, ensuring efficient energy use.

60. **Debris Disposal System**

- The debris disposal system handles the disposal of captured debris, either by deorbiting it to burn up in the Earth's atmosphere or transporting it to a designated graveyard orbit. The disposal method is determined based on the debris size and composition.
- The system ensures compliance with international space regulations, minimizing the risk of creating additional debris.

61. Function and Operation

62. The system operates autonomously, with the AI making real-time decisions based on sensor data. The following steps outline the typical operation sequence:

63. **Debris Detection**

- The sensors continuously scan the environment for space debris. Upon detecting debris, the AI processes the sensor data to determine its size, trajectory, and risk level. The AI uses advanced algorithms to filter out false positives and focus on high-risk debris.

64. **Navigation and Approach**

- The AI calculates the optimal path to the detected debris, ensuring collision avoidance with other space objects. The autonomous navigation system adjusts the spacecraft's trajectory in real-time to approach the debris safely. The navigation system uses data from the sensors to update its path continuously, avoiding obstacles and ensuring a safe approach.

65. **Capture Mechanism Deployment**

- Once in proximity to the debris, the AI selects the most suitable capture mechanism. The robotic arms, nets, or harpoons are deployed to securely capture the debris. The AI uses sensor data to position the capture mechanism accurately, ensuring a successful capture.

66. **Debris Disposal**

- Captured debris is either deorbited to burn up in Earth's atmosphere or transported to a designated graveyard orbit. The disposal method is chosen based on the debris characteristics and compliance with space regulations. The system executes a controlled disposal process, ensuring that the debris does not pose a hazard to operational satellites or other space missions.

67. **Energy Management**

- Throughout the operation, the energy management system optimizes power distribution to ensure continuous functionality. Solar panels recharge the energy storage units, while the AI manages power allocation to critical components. The system prioritizes power for navigation, debris detection, and capture operations, maintaining overall energy efficiency.

68. Advantages and Improvements

69. The Autonomous Space Debris Cleanup System offers several advantages over existing technologies:

- **Comprehensive Detection**: The multi-sensor approach provides robust and accurate debris detection and tracking, enhancing situational awareness.
- **AI-Driven Autonomy**: The integration of AI algorithms enables real-time decision-making and autonomous operation, reducing the need for human intervention.
- **Versatile Capture Methods**: The use of multiple capture mechanisms allows the system to handle a wide variety of debris sizes and shapes, improving its adaptability.
- **Energy Efficiency**: The optimized energy management system ensures sustainable operation during extended missions, reducing the need for frequent resupply missions.

- **Compliance and Safety**: The system adheres to international space regulations, ensuring safe and responsible operations. The AI continuously monitors compliance and adjusts operations to prevent collisions and minimize risks.

70. Embodiments and Alternatives

71. Various embodiments of the system can be implemented to enhance its versatility and scope. For instance, alternative configurations of the capture mechanisms can be designed to handle specific types of debris more efficiently. Additionally, the AI algorithms can be further refined to improve detection and classification accuracy.

- **Example 1: High-Density Debris Field Management**
  - In scenarios where the system operates in a high-density debris field, the AI algorithms prioritize debris based on size and collision risk. The system may deploy multiple capture mechanisms simultaneously to manage the high debris density effectively.
- **Example 2: Extended Mission Duration**
  - For extended missions, the energy management system includes additional solar panels and high-capacity batteries to ensure continuous operation. The AI optimizes energy usage to extend the mission duration, balancing power between detection, navigation, and capture operations.
- **Example 3: Adaptive Learning**
  - The AI algorithms incorporate adaptive learning techniques, allowing the system to improve its performance over time. By analyzing past encounters, the AI updates its models to enhance detection accuracy and optimize capture strategies.

- **Example 4: Multi-Satellite Coordination**
  - In a multi-satellite setup, multiple debris cleanup systems coordinate their operations to manage larger areas. The AI algorithms ensure that each satellite covers a specific region, optimizing overall debris removal efficiency.
- **Example 5: Dynamic Obstacle Avoidance**
  - The navigation system includes dynamic obstacle avoidance capabilities, enabling the system to navigate through complex debris fields. The AI continuously updates the navigation path, avoiding collisions and ensuring safe operation.

72. By providing a detailed description of the system's components, functions, and operations, the "Autonomous Space Debris Cleanup System" patent application establishes a clear and comprehensive understanding of the invention, supporting its claims of novelty and non-obviousness.

Claims

1. An autonomous space debris cleanup system for detecting, capturing, and removing space debris from Earth's orbit comprising:

    A central control unit with integrated AI algorithms for debris detection, tracking, and classification;

    Multiple detection sensors including radar, lidar, optical cameras, and infrared sensors for comprehensive debris detection;

    Robotic capture mechanisms including robotic arms, nets, and harpoons for capturing debris;

    A debris disposal system for deorbiting debris, storing it in a container, or transporting it to a graveyard orbit;

    An autonomous navigation system for maneuvering the cleanup spacecraft safely around other space objects.

2. The space debris cleanup system of claim 1, wherein the AI algorithms analyze sensor data to identify and classify debris based on size, trajectory, and risk level.
3. The space debris cleanup system of claim 1, wherein the robotic capture mechanisms are designed to handle debris of different sizes and shapes.
4. The space debris cleanup system of claim 1, wherein the system operates autonomously using AI to make real-time decisions on debris capture and disposal.
5. The space debris cleanup system of claim 1, wherein the user interface allows ground control to monitor system status, view debris tracking data, and override autonomous operations if necessary.

6. The space debris cleanup system of claim 1, wherein the energy management system includes solar panels and energy storage for continuous operation.
7. The space debris cleanup system of claim 1, wherein the safety protocols ensure the system avoids collisions with operational satellites and space stations.
8. The space debris cleanup system of claim 1, wherein compliance with international space regulations and guidelines ensures safe and responsible debris removal operations.

Abstract

1. An autonomous space debris cleanup system designed to detect, capture, and remove space debris from Earth's orbit. The system employs advanced sensors, AI for debris detection and tracking, and robotic mechanisms for debris capture and disposal. Features include autonomous operation, efficient energy management, and compliance with international space regulations. This innovative solution aims to enhance the safety of space operations by effectively managing space debris.