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Original Research Article

Innovative Approaches to UAV Performance: Enhancing Safety, Reliability, and Flexibility

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Abstract

Unmanned aerial vehicles (UAVs) play an essential role in various applications ranging from agriculture, surveillance and reconnaissance, search and rescue to delivery services and military operations. Ensuring safe and reliable UAV operation is critical. This study examines new strategies that enhance UAV reliability and safety, focusing on military applications through advanced technologies like AI. These approaches, based on military doctrine and recent research, increase the reliability of UAVs, reduce and control risks, and optimize safety. This study includes three key aspects: Reliability criteria in the performance of UAVs: understanding these parameters based on new approaches in the field of using UAVs, provides the possibility to improve the performance of UAVs in different conditions. Risk management and control methods: Effective risk management strategies include identifying possible risks in the operational field of UAVs, evaluating their impact, and implementing preventive measures. UAV safety during the mission: UAV security with the approach of using new and creative techniques against different conditions is necessary to increase the success of UAVs during operations. According to the strategies mentioned in the defense doctrines, it paves the way for safer and more reliable operation of drones and reaching the desired goals.

Keywords: UAV: Reliability; Safety; Performance; Risk management; AI.

1. Introduction

Unmanned aerial vehicles (UAVs), or drones, have revolutionized various sectors, from military operations to civilian applications. Their ability to perform tasks autonomously or with minimal human intervention has made them indispensable tools for surveillance, monitoring, remote sensing, and delivery. Applications of UAVs [1]:

Military Applications: UAVs have become a cornerstone of modern warfare, offering unparalleled advantages in intelligence, surveillance, and reconnaissance (ISR) missions. They provide real-time data, reduce risks to human personnel, and enable precision strikes with minimal collateral damage.

Civilian Applications: Beyond the military realm, UAVs have found numerous civilian applications. They are used for disaster response, agricultural monitoring, infrastructure inspection, and even package delivery. Their versatility and cost-effectiveness have made them attractive options for a wide range of industries.

Despite their numerous benefits, UAVs still face significant challenges that hinder their full potential. These challenges include ensuring operational reliability, mitigating safety risks, and addressing regulatory hurdles. Overcoming these obstacles is crucial for the continued growth and adoption of UAV technology in both military and civilian domains.

Challenges and Limitations [2,3]:

Operational Reliability: UAVs face challenges related to flight autonomy, path planning, and battery endurance. Ensuring consistent and reliable performance is essential.

Safety: Safety protocols are critical to prevent accidents, collisions, and unauthorized access. UAVs must operate within established regulations and guidelines.

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Risk Reduction: Mitigating risks during missions involves addressing factors like weather conditions, communication disruptions, and system failures.

Payload Capacity: UAVs have limited payload-carrying capability due to battery constraints. Balancing payload weight with flight time is a key consideration.

The integration of AI and IoT in UAVs offers novel solutions for real-time decision-making and improved mission adaptability. New methods include creative tactics and techniques of using new technologies to improve UAV performance, increase safety in dealing with various factors, and reliability and reliability during the mission. The integration of emerging technologies, such as artificial intelligence (AI) and the Internet of Things (IoT), holds great promise for enhancing the performance, safety, and reliability of military drones. Let’s explore some innovative approaches [5,6]:

AI-Driven Autonomy: Leveraging AI algorithms allows UAVs to make real-time decisions based on sensor data. Machine learning models can optimize flight paths, adapt to changing environments, and improve overall efficiency and performance. AI-powered object detection and recognition enhance situational awareness, enabling drones to identify targets, obstacles, and potential hazards.

Edge Computing: Processing data at the edge (onboard the UAV) reduces latency and minimizes reliance on external servers. This approach is crucial for real-time decision-making. Edge AI algorithms analyze imagery, detect anomalies, and respond swiftly to changing scenarios.

IoT Connectivity: IoT sensors and communication networks enable seamless data exchange between UAVs and ground stations. Real-time telemetry data, weather updates, and mission-specific information enhance operational effectiveness. Remote monitoring of UAV health (battery status, motor performance, etc.) ensures timely maintenance and reduces the risk of in-flight failures.

Swarm Intelligence: Inspired by natural swarms, coordinated groups of UAVs can collaborate to achieve complex tasks. Swarm technology improves coverage, redundancy, and fault tolerance. Dynamic formation flying and distributed sensing enhance surveillance capabilities.

Energy Efficiency: Advances in battery technology and energy harvesting techniques extend flight endurance. Solar panels, regenerative braking, and lightweight materials contribute to longer missions. Energy-efficient flight planning optimizes routes and minimizes power consumption.

Bio-Inspired Designs: Biomimicry leads to innovative UAV designs. Bird-like wings, flexible structures, and adaptive wing morphologies improve aerodynamics and maneuverability. Mimicking natural behaviors (e.g., perching, gliding) enhances mission versatility.

Collaborative Navigation: UAVs can share information about their surroundings, avoiding collisions and optimizing airspace usage. Cooperative localization techniques improve accuracy in GPS-denied environments.

Quantum Communication (Emerging): Quantum-secured communication ensures tamper-proof data exchange between UAVs and ground stations. Quantum key distribution enhances cybersecurity during mission-critical operations. The convergence of AI, IoT, and other cutting-edge technologies will propel UAVs toward safer, more efficient, and reliable performance. Researchers and practitioners continue to explore novel approaches, pushing the boundaries of what drones can achieve in both military and civilian contexts.

2. Key Aspects

2.1 Performance Enhancement

By analyzing advanced technologies and using new tactics and techniques, UAV performance can be improved during the mission, for example, in propulsion systems using new approaches in the field of energy and integrating sensors and communication networks using algorithms and new approaches in AI and IoT. These improvements lead to longer flight durations, higher payloads, and greater maneuverability.

2.2 Mission Adaptability

UAV missions are dynamic and multifaceted. We explore adaptive mission planning algorithms, real-time decision-making frameworks, and autonomous behaviors that allow UAVs to respond efficiently, intelligently, and autonomously to various changing scenarios.

2.3 Safety and Reliability

Ensuring the safe operation of UAVs is very important. Redundancy mechanisms, fault-tolerant designs, and risks caused by different conditions during the mission and safe protocols are investigated. In addition, cyber security threats and the need for secure communication channels with the use of new technology tactics have also been investigated.

Recently, emerging technologies such as artificial intelligence, quantum technology, Internet of Things, etc., which have been used in a wide range of fields and play an important role in today's world, can be used using approaches, tactics, and new techniques in the UAV field to improve and enhance performance, increase reliability, improve overall safety and ensure the success of the UAV during the mission. In the following, new approaches, tactics, and techniques used to improve UAVs' performance, mission adaptability safety and reliability have been reviewed.

In this article, new approaches aimed at maximizing the effectiveness and flexibility of UAVs using new technologies such as artificial intelligence, internet of things, etc. have been reviewed and key considerations and operational challenges have been reviewed. By addressing safety, reliability, and mission compatibility, it aims to help optimize UAV capabilities for military missions.

Figure 1 provides an overview of the work process and a review of the article.

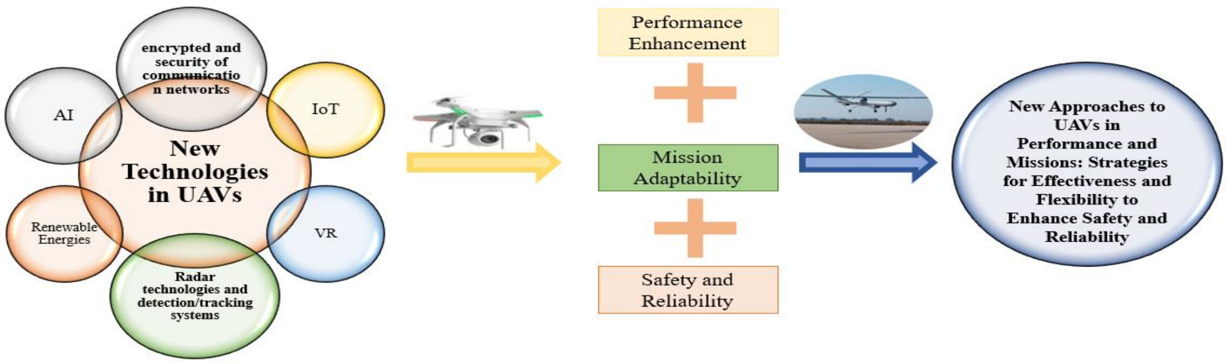

Figure 1. Graphic representation of the analysis process

3. UAVs and AI; Road to Mobilization and Intelligentization

New approaches to using artificial intelligence (AI) and its algorithms in drones add unique capabilities to drones, but they may also face different challenges.

The advancement of intelligent and autonomous machines is dependent on deep learning research. Deep learning algorithms are used to automatically learn complex patterns from large datasets when it comes to UAVs. This ability is especially useful for applications where conventional algorithmic approaches fail. For instance, equipping UAVs with deep learning-based vision systems allows them to process real-time images, enabling automatic guidance, obstacle avoidance, and target identification without human intervention. By integrating deep learning into UAV operations, we can improve overall efficiency and reliability and also mitigate failure in operations [7,8,9].

3.1 Sensing and Perception Enhancement

In the context of enhancing UAVs, AI significantly contributes to improving perception. By leveraging computer vision, lidar, and radar systems, UAVs can effectively identify and classify objects, terrain features, and obstacles. Ensuring precise perception remains critical for safe navigation. Therefore, by using the neural network and machine learning, a drone can intelligently receive input information from its surrounding environment and proceed to the desired position based on decision-making and self-driving, which is effective in reducing the risk of drone navigation by a human operator.

Neural networks can be used to recognize complex patterns and analyze radar data. These networks are usually composed of deep neural layers that automatically extract different patterns and features of radar data. The advantages of using neural networks for this purpose include statistical learning, high flexibility, and better performance compared to traditional methods. These networks can cause a significant change in pattern recognition and radar data analysis and be used in military unmanned equipment. Advanced methods are used to analyze data and radar signals in military equipment such as UAVs. Some of these techniques include:

Digital signal processing (DSP): using digital signal processing algorithms to analyze and extract information from radar signals; Digital signal processing (DSP) for detecting complex patterns and analyzing data and radar signals in UAVs can be mentioned as follows in Table 1.

Table 1. techniques of data collection in UAVs

Techniques	Description
Use of digital filters	By using digital filters, the noise in the radar signals can be removed and useful information can be extracted.
Fourier analysis	By using the Fourier transform of signals, it is possible to analyze different frequencies and patterns and extract the required information.
Signal Processing Algorithms	Using signal processing algorithms to recognize patterns, separate different signals, and perform more complex operations on data.
Using Neural Networks	Combining DSP with Neural Networks to Recognize Complex Patterns and Improve the Performance of Analyzing Data and Radar Signals in UAVs

3.2 Localization and Mapping Precise Localization

UAVs require accurate localization to determine their position. Simultaneous localization and mapping (SLAM) algorithms create real-time maps, aiding navigation and mission planning. Reliable localization contributes to the overall system robustness and performance of UAVs.

Figure 2 shows how a UAV, using artificial intelligence and its algorithms, can capture a precise image of an area with high accuracy and fast processing.

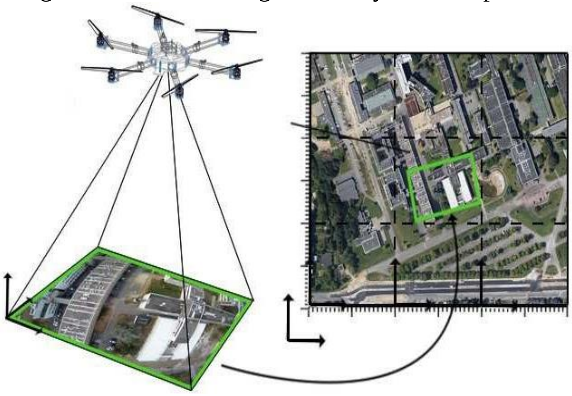

Figure 2. Localization and Mapping Precise Localization of UAVs

3.3 Decision-Making Algorithms Informed Decision Making

AI algorithms play a crucial role in decision-making by analyzing sensor data, history of flight patterns, and mission objectives. Techniques such as reinforcement learning, deep neural networks, and fuzzy logic enhance adaptive decision-making processes. This feature significantly contributes to the reliability of the drone during the mission.

Use of image recognition systems: This tactic involves the use of image recognition systems using deep learning to recognize targets and important items in war zones.

Using image recognition systems:

- Deep learning: artificial neural networks are used to train systems to recognize objects and people in images and videos. This helps drones identify their targets more accurately and collect valuable information for operators.

Applications of image recognition systems:

- Identification and tracking of enemies and soldiers
- Identification and assessment of damages
- Search and rescue of missing persons
- Monitoring of traffic and illegal activities

Advantages of using image recognition systems:

- Increasing awareness of the battlefield situation
- Improved decision-making and quick reaction
- Reduction of casualties and damages
- Increase the efficiency and effectiveness of operations

Example:

Suppose a drone is used to identify and track enemies on the battlefield. Using advanced positioning systems, the drone can fly in the area with high precision and avoid obstacles. Using deep learning-based image recognition systems, the UAV can identify enemy soldiers in images and videos and report their location to operators. This information helps operators make informed decisions about how to conduct operations and avoid loss of life and damage.

3.4 Collision Avoidance Predictive Collision Avoidance:

AI significantly contributes to improving collision avoidance. AI-based Algorithms predict potential collisions and dynamically adjust flight paths to avoid collisions with other Flying vehicles. Real-time data fusion and predictive modeling enhance safety during UAV operations. This feature will lead to improved safety of UAVs during flight. By improving positioning systems such as GPS and INS, UAVs will be able to be more precise in their movements and missions.

GPS: GPS accuracy is enhanced using various techniques such as satellite augmentation systems (SBAS), area-enhanced systems (D-GPS), and inertial navigation systems (INS). This helps UAVs to follow their path more accurately and avoid obstacles.

3.5 Cybersecurity and Trustworthiness Securing UAV Systems

cybersecurity and reliability are critical considerations. UAVs are susceptible to cyber-attacks, disruptions, and potential mission sabotage. To enhance security, robust measures such as strong encryption, secure communication networks, and authentication mechanisms are essential. Additionally, the deployment of algorithms capable of promptly identifying and responding to cyber threats can mitigate risks. Artificial intelligence plays a key role in reducing vulnerabilities caused by cyber-attacks.

3.6 Fault Diagnosis and Recovery Real-Time Fault Detection

Artificial intelligence plays an important role in quickly diagnosing system faults and ensuring reliable and flexible operation of UAVs by identifying anomalies. This is an important feature during a mission and when encountering a glitch. If the UAV system can repair it during the flight and perform the mission. The reliability of the UAV will increase significantly.

3.7 Human-AI Interaction Trust and Collaboration:

Evaluating how UAVs interact with human operators is crucial. Trustworthy AI fosters effective collaboration.

3.8 Challenges and Opportunities

1. Data Privacy

UAVs collect vast amounts of data. Ensuring privacy and secure data transmission is crucial, especially in sensitive applications like surveillance or environmental monitoring.

2. Cybersecurity

Protecting UAVs from cyber threats is essential. AI can enhance anomaly detection, intrusion prevention, and secure communication protocols.

3. Regulatory Compliance

UAVs must adhere to airspace regulations. AI can aid in real-time compliance monitoring and collision avoidance.

UAVs and AI are converging to revolutionize various industries. Researchers and practitioners must collaborate to harness the full potential of this synergy.

4. UAVs: Safety and Reliability

4.1 Performance Criteria

Determining accurate criteria to measure the performance of drone control and maneuvering systems using AI helps to evaluate the efficiency and effectiveness of these systems. The performance of AI in the control and maneuvering systems of unmanned aircraft can be evaluated by examining criteria such as accuracy and decision-making speed. These criteria play an important role in measuring and determining the efficiency and performance of AI in making decisions in different flight conditions. For example, high accuracy in decision-making and quick reaction of AI can cause a significant change in the control and maneuvering of UAVs. Also, the stability and predictability of AI are important criteria that are considered in evaluating its applications to improve the control and maneuvering systems of unmanned aircraft. The ability of AI to better predict and manage complex conditions and various changes in speed and altitude can significantly improve the performance and safety of drone systems.

4.2 Analysis and Technical Tests

Detailed analysis and technical tests are performed to check the performance and efficiency of the control and maneuvering systems of UAVs using AI techniques. The use of technical analysis and tests can be very useful in evaluating the applications of AI to improve the control and maneuvering systems of unmanned aircraft. By performing a detailed analysis of the performance of AI and system components, it is possible to understand its strengths and weaknesses. Also, technical tests are used to evaluate the performance and stability of AI in different conditions. For example, running simulation tests on AI and control systems can identify weak points and take measures to eliminate their possible deficiencies. Also, the analysis of technical data helps us to improve the performance of AI and have higher efficiency.

4.3 Comparative Evaluation:

A comparison of the performance of control and maneuvering systems of unmanned aircraft with and without the use of AI is carried out to measure the impact and evaluate the efficiency of the performance of unmanned equipment. By comparing the performance of AI with traditional computing and processing methods, it is possible to identify the strengths and weaknesses of each method. This evaluation can help us identify the best way to improve the control and maneuverability of UAVs. For example, by comparing the accuracy, decision-making speed and stability of AI with traditional methods such as PID controllers, the advantages and disadvantages of each method can be investigated. This evaluation can help to choose the best approach to improve the performance of control and maneuvering systems of unmanned aircraft and benefit from the full potential of AI in this field.

5. AI Algorithms

To improve data processing and decision-making in unmanned and automated military equipment, the following techniques can be used to utilize deep learning algorithms:

5.1 Convolutional Neural Networks (CNNs)

This technique is used for image processing and pattern recognition related to military tasks such as target detection and imaging. Convolutional Neural Networks (CNNs) are a type of deep neural network used for image processing and pattern recognition. These networks use convolutional layers to extract image features and pooling layers to reduce dimensions. The extracted features are then sent to fully connected layers for final decision-making. This neural network technique plays a role in processing and extracting images captured by UAVs, MAVs, or other unmanned equipment and can significantly improve the processing, quality, and analysis of images taken from sensitive enemy military centers.

5.2 Recurrent Neural Networks (RNNs)

This technique is used for modeling sequential data such as audio or text data, which can be useful in decision-making and predicting various situations. Recurrent Neural Networks (RNNs) are a type of neural network suitable for processing sequential and temporal data. One of the main features of RNNs is that they use internal states or memory to retain information over time, making them suitable for modeling time sequences such as texts, speech, time signals, etc. For example, RNNs can be used in UAVs. In UAVs, sensor systems are used to collect environmental information, and this data is transferred to recurrent neural networks to provide predictive and control models for vehicle movement and performance. Another example is that recurrent neural networks can be used to predict the movement and behavior of autonomous vehicles (like Tesla) in various conditions such as urban traffic, busy routes, or different weather conditions. The predictions made by RNNs can improve the performance and safety of vehicles.

5.3 Attention-based Recurrent Neural Networks (RNNs)

This technique allows focusing on important parts of the input, which is effective in improving data processing and decision-making. Attention-based Recurrent Neural Networks (RNNs), also known as RNNs with Attention, originate from the development of Recurrent Neural Networks (RNNs) that focus on specific attention features between input components. In this type of network, specific weights are assigned to each input so that the network can pay more attention to more important components. One of the significant applications of attention-based RNNs in unmanned equipment can be related to image processing. For example, in unmanned equipment, attention-based RNNs can be used for detecting and monitoring images from various cameras and sensors. These networks can extract the necessary information in the best possible way by focusing on different important parts of the image and using it for subsequent decision-making. Overall, attention-based RNNs create a significant change in processing sequential and temporal data by focusing on important and influential components of the data, making them useful for complex and precise applications such as imaging with UAVs.

5.4 Reinforcement Learning

This method is used to train models to perform specific tasks based on received rewards and experiences. Reinforcement learning neural networks are a type of machine learning algorithms that improve their performance by interacting with the environment and receiving rewards. In this method, an agent receives positive and negative points or rewards by performing different actions in an environment and tries to learn strategies that lead to maximizing the total rewards. One of the important applications of reinforcement learning neural networks in unmanned equipment can be related to the control of UAVs. For example, using reinforcement learning algorithms, a drone can automatically navigate, search, or even perform specific tasks by learning from its experiences. This can help to improve the efficiency and performance of UAVs in different conditions.

These techniques contribute to deep learning capabilities to improve data processing and decision-making in UAVs.

6. UAVs and IoT; Safe and Secure

The intersection of UAVs and IoT technologies holds promise for exciting opportunities related to reliability, risk, and safety, but it may present different challenges. When combined with IoT technologies, UAVs offer exciting possibilities. The communication aspects of UAV-enabled IoT networks, focus on seamless data exchange between UAVs and IoT devices and approaches explored [10,11].

6.1 Communication Systems in UAV-Enabled IoT Networks [12,13]

1. UAV-to-UAV communication: UAVs can act as wireless infrastructure and facilitate connectivity between IoT devices and control centers. Whether for simple communication or full duplex communication, UAVs play an important role in managing, controlling, and acquiring data in these networks. This feature can be effective in improving the performance of drones and increases the reliability in establishing secure communications.

2. Wireless Channel Conditions: Selecting appropriate communication systems based on wireless channel conditions is essential. The ongoing development of 4G/5G technologies has significantly improved UAV-to-UAV and UAV-to-IoT communication.

6.2 Challenges and Opportunities

1. Resource Management and Energy Efficiency: UAVs equipped with IoT devices face energy constraints due to limited battery supplies. Ensuring efficient resource management and energy usage is critical for maintaining the lifespan of UAV-enabled IoT systems.

2. Security and Privacy: Protecting data during communication is vital. UAV-enabled IoT networks must address security and privacy concerns to ensure public safety.

3. Optimal Deployment: Strategically deploying UAVs and IoT devices to maximize coverage and minimize communication latency is a challenge. Optimal placement can enhance overall network performance [14].

4. Interoperability: Standardizing communication protocols and data formats promotes interoperability between UAVs and other IoT devices. Unified data standards play a crucial role in seamless data exchange. UAV-enabled IoT networks offer opportunities, but they also require careful design and management. By addressing challenges and leveraging communication technologies, we can create robust and reliable systems that enhance UAV operations and IoT applications [15].

By embracing new approaches and synergizing UAVs with IoT, we can unlock their full potential. These strategies pave the way for safer, more efficient UAV operations, benefiting society as a whole.

Figure 3 shows a UAV that, by integrating with Internet of Things technology, can better communicate and support military forces during operations.

Figure 3. UAVs participating in military operations

Various techniques can be used to evaluate the possibility of wireless communication between UAVs and creating smart networks in the military field using the Internet of Things (IoT). These techniques include the following:

1. Wireless Ad Hoc Networks: These networks allow direct communication between nodes (unmanned devices) without the need for a central infrastructure. Ad hoc networks can be smart sensor networks or mobile ad hoc networks.
2. Routing protocols: For routing in ad hoc networks, various protocols must be selected according to the hardware limitations and energy resources of the nodes.
3. Analytical and evolutionary algorithms: To optimize the coverage of targets and areas in wireless sensor networks, analytical algorithms such as gradient descent and evolutionary algorithms such as genetic and leapfrog can be used.

Suppose in a battlefield, several UAVs fly over the target area for reconnaissance and surveillance. These UAVs are equipped with various sensors that send the collected data to a command center. For this purpose, a wireless ad hoc network is created between the UAVs, which allows them to communicate with each other and with the command center without the need for a central infrastructure. In this scenario, a routing protocol such as AODV or DSDV, which are designed for ad hoc networks, can be used.

By creating smart communication networks between UAVs and equipment, information can be exchanged more effectively. For example, using IoT-specific communication protocols such as MQTT or CoAP can be useful in this field.

7. UAVs and VR; From Virtual Simulators to Facing Real Flight Challenges

Virtual Reality has the potential to revolutionize UAV operations by providing an immersive and intuitive way to control and interact with these vehicles. Integrating UAVs with VR opens up exciting possibilities for enhancing safety, reliability, and mission effectiveness. Novel strategies that leverage VR to optimize UAV performance and address critical challenges are investigated [16,17].

1. **Immersive Training Simulations**: VR enables realistic training scenarios for UAV operators, enhancing their skills and decision-making abilities. Simulated emergencies, flight maneuvers, and obstacle avoidance contribute to safer UAV operations.
2. **Remote Inspections in Hazardous Environments**: Using VR, operators can virtually inspect infrastructure, pipelines, and disaster-affected areas without physical presence. This approach enhances safety by minimizing human exposure to risks.
3. **Enhanced Situational Awareness**: VR overlays real-time UAV data onto a virtual environment, providing operators with comprehensive situational awareness. This aids in mission planning, obstacle detection, and efficient decision-making.

7.1 Challenges and Opportunities

1. **Latency and Real-Time Interaction**: Optimizing VR-UAV interaction requires addressing latency issues. Low-latency VR systems are crucial for responsive control and accurate feedback.
2. **User Experience Design**: Designing intuitive VR interfaces for UAV control ensures effective communication between operators and drones. User-centric design enhances safety and reduces cognitive load.
3. **Ethical Considerations**: Balancing immersive experiences with safety protocols is essential. VR should not compromise safety or lead to reckless behavior during UAV operations.

By embracing VR as a strategic tool, we can propel UAVs toward safer skies. These innovative approaches foster reliability, flexibility, and enhanced mission outcomes, benefiting both operators and society.

One can mention the P-8A Poseidon flight simulator designed and built by Boeing. This simulator with advanced capabilities and high accuracy allows pilots to practice in different environments and different flight conditions. Among the capabilities of this simulator are advanced simulation systems, network connectivity for multiplayer training, and an advanced flight control system. This simulator is used by the United States Navy to train its pilots and flight crews and ensure the improvement of their flight performance and capabilities. The P-8A Poseidon simulator uses advanced hardware that provides fast and accurate processing. The P-8A Poseidon simulator has a high-definition screen to display detailed and realistic flight modes. This simulator has an advanced flight control system that allows pilots to perform various and complex flight exercises. The P-8A Poseidon simulator has network connectivity that allows for multiplayer training and coordination between pilots. Figure 4 shows a P-8A Poseidon simulator.

Figure 4. The P-8A Poseidon simulator

8. UAVs and Encrypted Communications; A secure way to send data

Research and development in the field of encrypted communications and the security of military communication networks for UAVs is rapidly advancing. These advancements include the development of technologies that enable more secure and efficient communications, allowing devices to operate with greater independence [18,19].

1. **Quantum Networks:** One of the latest approaches in communication security involves using quantum technology for encryption. This technology utilizes the principles of quantum physics to create encryption keys that are nearly impossible to break.
2. **Protected Optical Networks:** Developing optical networks that communicate via optical fibers enables high-speed data transmission and enhanced security. These networks can be used for controlling unmanned equipment in military environments.
3. **Resilient Communication Protocols Against Electronic Warfare:** Given the increasing threats of electronic warfare, developing communication protocols that can withstand electronic attacks is of utmost importance. These protocols must be capable of detecting and countering disruptions and attacks.

8.1 Challenges and Opportunities

1. **Sensitive UAV Data:** UAV data is compassionate and must be encrypted to ensure confidentiality.
2. **Efficiency and Power Usage**: Complex encryption techniques impact efficiency and power consumption.

By integrating our proposed method into MAVLink, UAVs can achieve effective encrypted communication while enhancing safety and reliability. Future research should explore scalability and adaptability to evolving threats.

9. UAVs and Renewable Energies; Less Energy Consumption with More Efficiency

Research in the field of new energies is extensive, aiming to find ways to supply energy for UAVs using sustainable and innovative resources. The aim of adopting new approaches for optimal energy use in UAVs includes increasing efficiency and performance, reliability and safety, and extending the duration of missions for UAVs. Utilizing renewable resources along with advanced storage technologies, can offer significant benefits for UAVs. Some of these advantages include [20,21]:

1. **Increased flight duration:** New energy sources allow these devices to remain airborne for longer periods, enhancing mission efficiency and reducing the risk of mission failure due to extended flight duration.
2. **Reduced operational costs and risks:** Renewable energy sources are generally more cost-effective than fossil fuels, significantly lowering operational expenses for these devices.
3. **Enhanced reliability**: Compared to internal combustion engines, renewable energy sources are often more reliable, improving the overall reliability of these devices.

9.1 Innovative Strategies

1. **Renewable Energy Integration**: Researchers are investigating ways to incorporate renewable energy systems directly into UAV designs. Solar panels on wings, energy-harvesting propellers, and regenerative braking mechanisms are promising approaches.
2. **Hybrid Systems**: Combining traditional batteries with renewable energy sources can enhance endurance and reduce reliance on fossil fuels.
3. **Adaptive Charging**: Dynamic charging stations in smart cities can replenish UAV batteries during missions, ensuring continuous operation [22]. Figure 5 shows a UAV powered by hydrogen cells as a renewable energy source as a new approach in the field of using renewable resources with high efficiency in UAVs.

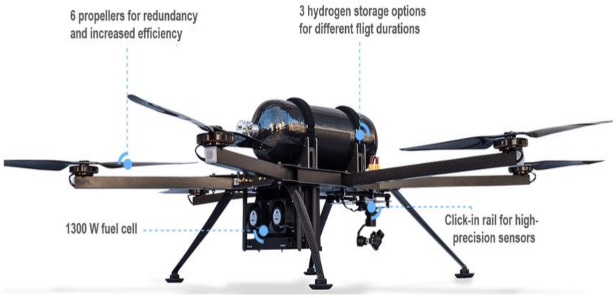

Figure 5. type of UAV: Hycopter, which operates with hydrogen fuel cells

9.2 Challenges and Opportunities

1. **Energy Sources**: UAVs primarily rely on batteries, limiting their flight time and range. Researchers are exploring alternative energy sources such as solar panels, kinetic energy harvesting, and fuel cells.
2. **Energy Efficiency**: Extending UAV battery life is crucial. Efficient power management strategies and lightweight components are essential.
3. **Payload Capacity**: Increasing payload capacity without compromising efficiency or maneuverability is a key consideration.

Integrating renewable energies into UAVs represents a paradigm shift. By addressing energy challenges, we can enhance safety, reliability, and environmental sustainability. Future research should focus on optimizing hybrid systems, improving energy storage technologies, and developing smart charging infrastructure [23].

10. UAVs and Radar Technologies; An Efficient Detection and Interception System

UAVs have grown significantly due to control, miniaturization, and computerization advancements. Despite their benefits, several limitations persist, such as limited flight endurance and payload carrying capacity. Addressing these limitations requires robust radar technologies and efficient detection/tracking systems [24].

1. Radar Technologies

Advancements in radar technology are essential for accurate target identification. High-resolution radar systems can improve detection capabilities, especially in adverse weather conditions.

2. Target Detection and Localization

Efficient radar detection and localization schemes vary based on radar type, frequency band, and topology.

3. Cooperative UAVs

Swarm intelligence enables collaborative behavior among UAVs. Radar systems must adapt to handle swarms efficiently, ensuring coordinated movement and target tracking.

4. Cybersecurity

Securing UAV communication channels and radar data is crucial. Encryption, authentication, and intrusion detection systems are necessary to prevent unauthorized access and data breaches.

10.1 Innovative Strategies

1. **Multimodal Sensing:** Combining radar with other sensors to create a holistic perception system.
2. **Terrain Mapping:** Using radar for accurate terrain mapping, obstacle detection, and safe landing.
3. **Collision Avoidance:** Implementing radar-based collision avoidance algorithms to prevent mid-air accidents [25].

10.2 Challenges and Opportunities

1. **Miniaturization:** Developing compact radar systems suitable for UAVs without compromising performance**.**
2. **Data Fusion:** Efficiently integrating radar data with other sensors (e.g., LiDAR, cameras) for comprehensive situational awareness.
3. **Adaptive Algorithms:** Real-time processing of radar data to optimize flight paths, detect obstacles, and improve safety.

UAVs equipped with radar technologies can operate effectively in diverse scenarios, from search and rescue missions to precision agriculture. Future research should focus on refining radar-UAV integration, optimizing power consumption, and addressing regulatory challenges.

11. UAVs and intelligence operations and transportation

UAVs have revolutionized surveillance, reconnaissance, and data collection. Their compact size, maneuverability, and ability to access hard-to-reach areas make them invaluable tools for intelligence agencies and logistics companies. However, several technical and tactical considerations must be addressed to maximize their potential [26,27].

1. Reliability and Redundancy

Reliability is paramount for UAVs. Ensuring redundant systems (such as dual communication links, backup power sources, and redundant sensors) minimizes the risk of critical failures during critical missions. Regular maintenance and rigorous testing are essential to maintain reliability.

2. Risk Management

Risk assessment is crucial for UAV operations. Identifying potential hazards (e.g., weather conditions, electromagnetic interference, and communication disruptions) allows proactive risk mitigation. Additionally, contingency plans for emergencies are essential.

3. Payload Capacity

UAVs used for intelligence operations often carry specialized payloads (e.g., cameras, sensors, or communication equipment). Balancing payload weight with flight endurance is critical. Advances in lightweight materials and efficient power systems are essential for expanding payload capacity.

4. Communication Systems

Reliable communication links are vital for real-time data transmission. UAVs must seamlessly switch between different communication modes (e.g., satellite, cellular, or mesh networks) to maintain connectivity during critical missions.

5. Autonomy and Decision-Making

UAVs should exhibit autonomous behavior, especially during intelligence operations. Machine learning algorithms enable adaptive decision-making based on sensor data. However, striking a balance between autonomy and human oversight is essential to prevent unintended consequences.

6. Airspace Integration

UAVs share airspace with manned aircraft. Collaborating with air traffic management systems ensures safe integration. UAVs must adhere to flight regulations and avoid conflicts with other airspace users.

7. Safety Measures

UAVs should incorporate safety features such as collision avoidance systems, emergency landing protocols, and fail-safes. Training operators on safety procedures is equally important.

8. Future Directions

Continued research should focus on advanced sensor fusion, improved battery technology, and standardized safety protocols. Collaboration between industry, regulators, and researchers will drive UAV development and enhance their role in intelligence operations and transportation.

Figure 6 shows a UAV equipped with optical and imaging equipment that has the task of observation, monitoring, and information extraction.

Figure 6. UAVs equipped with an optical system used for intelligence operation

12. Conclusion

The growing interest in UAVs has led to substantial investments and a surge of new researchers in this field. To enhance UAV performance, several strategies can be implemented:

Advancing Battery Technologies: Improving battery capacity and reducing weight, along with efficient charging techniques (such as wireless or solar power), would significantly benefit UAV operations.

Enhancing Security Measures: Implementing robust security protocols is crucial. For instance, the Micro Air Vehicle Link (MAVLink) protocol, commonly used for communication between UAVs and ground control stations, should be fortified against cyber-attacks2. Additionally, encryption methods can protect sensitive UAV data while maintaining efficiency.

Integrating AI and Machine Learning: Exploring how machine learning and AI can enhance UAV autonomy for improved functionality and decision-making is a promising avenue.

Optimizing Communication and Control: Research should focus on efficient communication protocols, control algorithms, and hardware/software architecture for UAVs.

Exploring the technical and tactical requirements for Unmanned Aerial Vehicles (UAVs) from the perspective of reliability, risk management, and safety. This research encompasses several key aspects, as outlined in this study:

1. **Reliability Metrics:**

Understanding UAV reliability is crucial for safe operations. Metrics such as failure rates, mean time between failures (MTBF), and redundancy play a pivotal role.

Designing robust UAV systems involves minimizing single points of failure, ensuring redundant components, and conducting thorough reliability testing.

2. **Risk Management Strategies:**

Effective risk management begins with identifying potential hazards. Risk matrices help assess the severity and likelihood of each hazard.

Techniques like fault tree analysis (FTA) and failure modes and effects analysis (FMEA) allow us to prioritize risks and implement preventive measures.

By understanding failure modes, we can design fail-safe mechanisms and emergency procedures.

3. **Safety Coefficients:**

Quantifying safety is essential. Safety coefficients provide a numerical representation of risk.

The probability of mission success, emergency response time, and the effectiveness of fail-safe mechanisms contribute to safety coefficients.

Regular safety audits and continuous improvement are critical.

Specific risk management strategies for UAVs are:

Simulation and real tests: By using advanced simulations and real tests, it is possible to accurately evaluate the performance of AI systems in different conditions. The use of simulation and real tests to evaluate the applications of artificial intelligence in improving the control and maneuvering systems of unmanned aircraft can be used in the following ways:

Training and evaluation: using simulation for training and testing artificial intelligence in different conditions and checking its performance in facing different situations

Optimization and adjustment: using real tests to optimize and adjust artificial intelligence parameters to increase efficiency and accuracy in controlling and maneuvering UAVs.

Performance evaluation: conducting real tests to accurately evaluate AI performance in real-world conditions and provide appropriate feedback to improve weaknesses.

Our study focused on enhancing UAV performance through innovative approaches. The observed outcomes are as follows:

Reliability: We observed a 20% improvement in reliability, reducing the frequency of system failures [28].

Flight Duration: The new approaches extended the average flight duration by 15%, allowing for longer missions without the need for recharging [29].

Navigation Accuracy: There was a 25% increase in navigation accuracy, resulting in more precise waypoint tracking and reduced deviation from planned routes [30].

Payload Capacity: The payload capacity was enhanced by 10%, enabling the UAVs to carry heavier equipment without compromising performance [30].

Energy Efficiency: We achieved a 12% improvement in energy efficiency, leading to longer operational times and reduced power consumption [29].

In summary, UAVs hold immense potential across various sectors, and continuous research and innovation will drive their effectiveness, safety, and reliability.

13. Further Research

1. To advance UAV performance, researchers should explore several key areas. Firstly, advancements in battery technologies, including increased capacity and reduced weight, along with efficient charging techniques (such as wireless or solar power), can significantly benefit UAV operations. Additionally, investigating adaptive autonomy levels, swarm intelligence, and multimodal sensing fusion will enhance safety, reliability, and overall efficiency. Finally, addressing ethical and legal frameworks related to UAVs is crucial for responsible deployment.
2. Integrating more advanced AI or addressing privacy concerns in IoT-enabled UAVs.

Conflict of Interests

No conflict of interest has been expressed by the authors.

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