Potentially Open Research Directions for Unmanned Aerial Vehicles

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Contributor: Khaled Telli , Okba Kraa , Yassine Himeur , Abdelmalik Ouamane , Mohamed Boumehraz , Shadi Atalla , Wathiq Mansoor

The open development axis for Unmanned Aerial Vehicles (UAVs) involves creating a collaborative ecosystem where developers, researchers, and users can work together to build open source platforms, tools, and standards for UAV design, development, and operation. This approach allows for greater innovation and flexibility in the UAV industry, including the integration of AI and ML algorithms to enhance autonomous flight and decision-making capabilities. Further challenges and open research directions can be elaborated upon in the following points.

UAV drone research direction open source projects

1. Integration of AI

AI algorithms are revolutionizing the way in which UAVs operate. By using these algorithms, UAVs can achieve improved autonomous flight and decision-making capabilities, which can result in more efficient and safer operations [1][2]. One-way AI and ML algorithms can be used in UAVs is through the development of advanced sensor systems. For example, computer vision and LIDAR can be integrated into UAVs to provide real-time data to the AI system [3]. This allows the UAV to make decisions based on its environment and dynamically react to changes. Computer vision can enable the UAV to recognize objects and people in its environment, which can be used to improve safety and prevent collisions. Meanwhile, LIDAR can provide detailed information about the UAV's surroundings, including the distance, size, and speed of the objects, which can be used to more effectively navigate complex environments.

Another way AI can be used in UAVs is through the optimization of flight paths. By using ML algorithms, UAVs can learn from past flights and optimize their routes to reduce energy consumption and increase efficiency. This can be achieved by analyzing data such as wind speed, temperature, and other environmental factors [4].

Generative AI and ChatGPT for UAVs

Natural language processing (NLP) models, like Chat Generative Pre-trained Transformer (ChatGPT) [5][6], are designed to understand natural language input from users and generate human-like responses. ChatGPT can be adapted to many robotics tasks, such as high-level agent planning [7] or code generation [8][9]. As such, it can serve as an intuitive language-based interface between non-technical users and UAVs.

"Efforts to incorporate language into robotics systems have largely focused on using language token embedding models, multi-modal model features, and LLM features for specific form factors or scenarios. Applications range from visual-language navigation [10], language-based human–robot interaction [11], and visual-language manipulation control" Ref. [12]. ChatGPT, for example, can be used via API libraries to enable many tasks [13], such as zero-shot task planning in drones, where it accesses functions that control a real drone and serves as an interface between the user and the drone [14]. This can allow non-technical users to easily and safely operate UAVs without needing specialized training.

A real drone was operated using ChatGPT through a separate API implementation, which offered a user-friendly natural language interface between the user and the robot, allowing the model to create intricate code structures for drone movement such as circular and lawnmower inspections [15]. Using the Microsoft AirSim [13][14] simulator, ChatGPT has also been applied to a simulated domain, where the possibility of a model being used by a non-technical user to operate a drone and carry out an industrial inspection scenario was investigated [15]. It can be seen from the snippet that ChatGPT can accurately control the drone by reading user input for geometrical clues and purpose.

2. Environmental Monitoring and Conservation

The utilization of UAVs for environmental monitoring and conservation presents a promising application of this advanced technology [16]. These unmanned aerial vehicles, equipped with high-resolution cameras and other cutting-edge sensors, offer immense potential for a wide range of purposes, including monitoring wildlife populations [17], tracking changes in ecosystems [18], and detecting environmental hazards [19]. By leveraging the capabilities of UAVs in these areas, researchers can greatly enhance the capacity to collect precise and reliable data, thereby gaining deeper insights into the overall health and well-being of the planet [20]. Such invaluable information empowers people to develop and implement effective conservation strategies, ensuring the preservation and safeguarding of the environment for future generations [21]. The use of drones in ecological and glaciological research in regions like Antarctica is on the rise, as demonstrated by studies [22][23][24]. Drones facilitate detailed geomorphological mapping, precise vegetation monitoring over expansive areas, and health indicator assessments. They enhance the identification and characterization of cryospheric features, including subsurface applications, and revolutionize faunal studies by enabling the non-invasive counting and morphometrics of diverse animal species [22]. UAV atmospheric surveys allow swift and versatile data collection, including aerosol sample collection. The design and development of platforms tailored to the harsh Antarctic environment have been crucial for the success of these applications. UAVs capable of collecting physical samples from remote or inaccessible areas are available, and further advances in autonomy and robustness will enhance their utility for Antarctic fieldwork [25]. UAV usage for environmental monitoring and conservation serves both planetary and human interests.

3. Urban Air Mobility (UAM)

UAM, an emerging field, holds immense promise for the future of transportation [26][27][28]. UAVs have the potential to revolutionize urban transportation by offering a rapid, efficient, and eco-friendly alternative to traditional ground-based systems [26]. However, realizing this potential necessitates significant technological advancements in navigation, autonomous flight, and safety systems. Moreover, the development of tailored air traffic management systems designed to address the unique challenges of urban environments is crucial for ensuring the safe and efficient operation of UAVs in densely populated areas [29]. With ongoing growth and investment in this domain, UAVs are poised to become a pivotal component of future urban transportation systems.

4. Miniaturization

In the UAV industry, miniaturization is a prominent trend that focuses on developing smaller and more compact drones capable of diverse applications [30]. These applications encompass search and rescue, delivery services, surveillance, and more. Nonetheless, accomplishing miniaturization necessitates substantial technological advancements, including the development of compact and efficient propulsion systems, as well as lighter and more durable materials. Consequently, miniaturization has emerged as a key area of research and development within the UAV industry, unlocking new possibilities for drone utilization across a wide range of fields.

5. Swarming and Cooperative Control

The open-development axis in the UAV industry focuses on establishing a collaborative ecosystem that brings together developers, researchers, and users to advance algorithms and techniques for the swarming and cooperative control of multiple UAVs, enabling them to perform complex tasks [31][32]. These tasks encompass a wide range of applications, including surveillance, search and rescue operations, and environmental monitoring. To achieve this, significant technological advancements are necessary, such as the development of robust communication protocols [31][33], distributed sensing and control systems [34], and adaptive decision making capabilities. For instance, the design of effective communication protocols facilitates seamless information exchange and coordination among multiple UAVs, enabling them to work together efficiently towards common objectives. Similarly, distributed sensing and control mechanisms empower each UAV to carry out specific tasks within a coordinated framework, greatly enhancing the efficiency and effectiveness of complex missions performed by UAV swarms. Additionally, the implementation of adaptive decision-making algorithms equips UAVs with the ability to make rapid and accurate decisions based on real-time data, further augmenting the capabilities of UAV swarms in various scenarios.

6. Beyond Visual Line-of-Sight (BVLOS) Operations

Beyond visual line-of-sight (BVLOS) operations refers to technologies that enable UAVs to operate beyond the visual line of sight of their pilot [35]. Achieving BVLOS capabilities requires the development of advanced sense-and-avoid systems capable of detecting obstacles and avoiding collisions [36]. Additionally, reliable communication and control protocols are necessary to ensure safe and efficient operations. To enable the widespread adoption of

BVLOS operations, regulatory frameworks must be established to ensure compliance with safety standards and mitigate potential risks [37].

7. Long-Range and High-Altitude Flights

Another area of development in the UAV industry is the advancement of long-range and high-altitude flights. This entails equipping UAVs with the ability to fly for extended periods and at greater altitudes. To achieve this, there is a need for the development of more energy-efficient propulsion systems capable of sustaining long flights [38]. Additionally, the integration of renewable energy sources—such as solar panels—into UAV designs is being explored to extend their range and increase their endurance [39][40].

8. Flight Safety

As the use of UAVs continues to grow across different applications, ensuring flight safety has become a crucial concern. In response, developers are actively working on integrating new technologies that can enhance the safety of UAV operations. For instance, there has been an increasing focus on developing collision avoidance systems [41][42] that can prevent mid-air collisions with other UAVs, manned aircraft, or obstacles in the environment. Additionally, automatic landing systems [43] can help reduce the risk of accidents during landing, while onboard obstacle detection and avoidance systems [41] can enable UAVs to detect and avoid obstacles during flight, reducing the risk of collisions. Such technologies are critical for ensuring the safe and responsible use of UAVs, as these can mitigate potential risks and prevent accidents.

9. UAV Suspension Payload Capabilities

UAV suspension payload refers to the development and optimization of suspension systems for UAVs that are capable of carrying various types of payloads, including heavier items such as medical supplies, food, and other essential goods. The suspension system plays a critical role in ensuring stable flight during missions that involve payload dropping, as it helps to mitigate vibrations and provide shock absorption to protect the payload and sensitive equipment on board [44].

Recent advancements in drone suspension payload technology have focused on improving the performance and efficiency of suspension systems, as well as integrating them with other components of the drone. Some examples of these advancements include the use of advanced materials and manufacturing techniques, the development of active suspension systems that can adjust to changing flight conditions in real time, and the integration of suspension systems with propulsion, control, and payload systems to ensure seamless operation and maximum efficiency.

Moreover, recent advances in controlling quadrotors with suspended loads have focused on developing new algorithms and control strategies that can handle the additional complexity and challenges introduced by the suspended payload [45][46][47]. Some recent studies have proposed methods to improve the accuracy and stability of quadrotors with suspended loads, including predictive control strategies and the use of adaptive learning algorithms [45][46][47]. These innovations in UAV suspension payload technology will lead to more efficient and reliable delivery and transport capabilities, further expanding the applications of UAVs in various fields.

10. Transformability or Convertibility

Transformability or convertibility is an emerging technology in the field of unmanned aerial vehicles that enables them to change their shape or configuration in flight [48][49][50][51]. This advancement has the potential to enhance the versatility and efficiency of UAVs by allowing them to adapt to different operational environments and missions. There are several approaches to achieving transformability in UAVs, including:

One important area of transformability that researchers will explore is the utilization of morphing wings. This innovative approach involves designing wings capable of changing their shape during flight to enhance efficiency and maneuverability [52]. By incorporating morphing wings technology, drones can adapt their wing configurations to varying flight conditions, such as alterations in altitude, speed, and wind direction. Through these adaptable wings, drones can optimize their aerodynamic performance and overall efficiency, thereby improving their range, endurance, and stability [53]. There are several mechanisms employed to achieve morphing wings, including shape memory alloys, smart materials, and mechanical systems. These mechanisms enable drones to adjust the wing angle, alter the curvature of the airfoil, or even completely change the wing shape. One notable example of the morphing wings technology is the “RoboSwift”, developed by the Delft University of Technology in the Netherlands. Resembling a swift bird in nature, this small drone has the ability to morph its wings during flight, allowing for enhanced efficiency and reduced noise. The RoboSwift has gained considerable recognition in the scientific community due to its innovative morphing wings technology and its potential applications in various fields, such as surveillance, environmental monitoring, and wildlife research. Its remarkable features have been highlighted in numerous research papers [54][55]. Another notable example is the “FlexFoil” developed by FlexSys Inc., Ann Arbor, MI, USA, an American engineering firm. The FlexFoil incorporates a unique “morphing trailing edge” technology, enabling the rear edge of the wing to bend and twist in response to changes in the airflow [56]. This design feature enhances the drone’s aerodynamic performance and adaptability to different flight conditions, resulting in improved efficiency. By harnessing the power of morphing wings’ technology, drones can revolutionize the field of aviation by achieving greater agility, range, and stability. The development of such transformative capabilities opens up new possibilities for various industries, from surveillance and monitoring to research and exploration.

The concept of foldable unmanned aerial vehicles (UAVs), equipped with collapsible arms or wings, presents an intriguing area for exploration [57]. This design feature leads to a decrease in the overall dimensions of the drones, thereby enhancing portability and facilitating more streamlined transportation and storage. Such foldable drones, including models like the Mavic Pro, DJI Mavic Air 2, Parrot Anafi, PowerVision PowerEgg X, and Robotics EVO, have gained substantial popularity due to their adaptability and convenience [58]. The ability of these drones to easily fold their arms or wings offers flexibility, allowing users to transport them in compact cases or bags. This feature not only improves portability, but also boosts the drones’ durability and protection during transportation.

Consequently, the potential damage is minimized, ensuring that the drones are well protected and ready for operation in a variety of environments and scenarios [59].

Moving on, reconfigurable airframes represents another avenue of transformation in UAVs. With reconfigurable airframes, drones have the ability to change their shape or configuration during flight to adapt to different missions or operational environments. This versatility can involve modifying their wing configuration, adding or removing payloads, or adjusting their center of gravity. By incorporating reconfigurable airframes, drones can cater to a wide range of mission requirements, making them more cost-effective and capable compared to traditional fixed-design drones. While reconfigurable airframes in UAVs are still an evolving technology, there are a few noteworthy examples of companies and organizations that are actively developing such drones [60]. For instance, roboticists from the University of Zurich and EPFL have developed quadrotors that feature foldable designs, allowing them to morph their shape in mid-air between “X” and “O” configurations [60][61]. These innovative designs demonstrate the potential of reconfigurable airframe drones, showcasing their adaptability and agility in various flight scenarios.

Additionally, the significant development in UAV technology is the incorporation ofvariable pitch propellers [62]. These propellers are equipped with blades that can adjust their angle or pitch during flight. Variable pitch propellers, also known as adjustable or controllable pitch propellers, provide a higher level of control over the drone’s flight and performance, particularly under challenging or dynamic conditions. By altering the pitch of the propeller blades, the drone can finely tune its thrust and lift, enabling it to maintain stable flight even under varying wind conditions, altitudes, or flight modes. This capability greatly enhances the drone’s maneuverability, efficiency, and overall performance across a wide range of applications, including aerial surveying, mapping, and inspection. Variable pitch propellers are commonly found in more advanced or specialized UAVs [63][64], such as industrial or military drones, where precise control and optimal performance are crucial. However, they are increasingly becoming accessible in consumer drones as well, allowing hobbyists and enthusiasts to leverage their benefits and enjoy greater control and versatility in their aerial endeavors.

Lastly, a significant advancement in UAV technology is the integration of transformable rotors [65][66]. UAVs equipped with transformable rotors have the ability to modify the configuration of their rotors during flight, enabling them to adapt to various flight conditions or mission requirements. This includes the capability to change the number or orientation of the rotors. The development of transformable UAVs holds tremendous potential in revolutionizing the field of unmanned aerial vehicles. It empowers UAVs to perform a broader range of missions with increased effectiveness and efficiency. One remarkable example is the VA-X4, which features four rotors that can tilt forward, transitioning from vertical takeoff and landing (VTOL) mode to forward flight mode. This design allows the UAV to achieve higher speeds of up to 200 mph, enabling it to more efficiently cover longer distances [65][66]. Another notable transformable rotor UAV is the Voliro Hexcopter developed by the ETH Zurich team [67][68]. This hexacopter utilizes multiple rotors capable of providing thrust in various directions, granting the drone the ability to translate freely and maneuver in complex environments. NASA’s Greased Lightning GL-10 [69] is yet another remarkable transformable rotor UAV. It can seamlessly transition between a vertical takeoff and landing (VTOL) mode and a fixed-wing mode, optimizing efficiency during forward flight. This UAV is equipped with ten electric motors powering ten rotors, enabling it to achieve high speeds and exceptional maneuverability. These examples demonstrate the immense potential of transformable rotor UAVs in expanding the capabilities and versatility of unmanned aerial systems, paving the way for more efficient and adaptable aerial missions across various industries.

Overall, transformable UAVs have the potential to greatly improve the versatility and efficiency of UAVs, enabling them to adapt to different operational environments and missions. By transforming their shape or configuration in flight, these UAVs can optimize their performance for different flight conditions and mission requirements, making them a valuable tool for a wide range of applications.

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