AUTONOMOUS DRONES: WHAT DOES THE FUTURE HOLD?

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Abstract. *This paper explores the impact of software innovation on autonomous drone control and the applications revealed in the process. The intended readers are technology enthusiasts who are looking forward to integrating and using drones in their daily operations and are intrigued by their future usage in science and business optimization. We introduced our readers to the world of autonomous unmanned aerial vehicles by first defining important terms and acronyms. Then we analyzed the core technologies necessary for autonomous drone control by explaining the key software components such as sensor fusion, path-planning and obstacle avoidance algorithms, and the communication protocols which are currently used. We discussed the advantages of autonomous drones compared to traditional drones and highlighted their enhanced safety, great efficiency, and the potential for new applications. Moreover, we examined the future challenges and possibilities of autonomous drones in the context of Artificial Intelligence advancements, cybersecurity concerns, legislative challenges, and rapid technical development. We investigated the potential business sectors that can further optimize their processes and what areas of improvement have to be studied to bring unmanned aerial vehicles to the necessary level of security and performance.*

Keywords: *ad-hoc networks, Bayesian inference, machine learning, path planning, sensor fusion, stochastic heuristic algorithms.*

Introduction

The acronym UAV stands for Unmanned Aerial Vehicle, commonly referred to as a drone. Over the years UAVs have proven to be useful in many areas such as surveillance, delivery services, and terrain exploration, due to their data-gathering capabilities through various sensors - referred to as sensor fusion; automation potential, and the possibility to operate independently of a pilot over preconfigured routes, or following other constraints through the use of so-called path planning algorithms [1].

We aim to evaluate the current and future state of autonomous UAVs by first giving an overview of algorithms and technologies that make autonomous drones possible, exploring their advantages over manually controlled drones, and evaluating future challenges and uses of autonomous drones.

Core technologies of autonomous drone control

The autonomous operation of drones (Unmanned Aerial Vehicles) depends on a complex system of software components. mainly: sensor fusion, path planning, communication, and coordination of drones.

Sensor Fusion is the process responsible for accurate navigation. It combines sensory data from GPS and LiDAR coordinates with camera images in order to produce enhanced data. At the base of this process, there are multiple algorithms which ensure safe and reliable environment perception. Common ones are Bayesian Inference and Kalman Filtering.

Bayesian Inference represents the drone position and velocity as a probability distribution. An initial belief about the drone's state is created based on the existing knowledge or on sensor calibration. With new sensor data arriving, a likelihood model is created and describes the probability of seeing the data in the context of the current state. At the base of this method, there is Bayes' theorem which updates the probability of an event when more data and evidence is gathered.

Kalman Filtering is a technique used to estimate the state of the vehicle given uncertain sensor readings. In the first phase, it works by combining this data and smoothing out the noise, therefore improving the accuracy of the estimated position. In the second part, once it receives new measurements, it updates the estimated values. It is a recursive algorithm, works in real-time, and doesn't require additional information from the past [2].

Path planning is a crucial process as it is responsible for generating optimal flight paths. It incorporates traditional techniques such as Dijkstra's algorithm. This algorithm considers the environment as a graph and finds the shortest path by iteratively selecting the node with the shortest distance from the source and updating the cost when a shorter path is found. A priority queue is kept in order to efficiently select the next node. The process is continued until either all nodes are visited or the shortest path is found. It is very well suited for static two-dimensional environments.

The Voronoi graph method, using seed nodes, divides space into cells, while making sure that points from each cell are closer to their seed node compared to any other node. This algorithm efficiently splits space around obstacles by creating polygons with equidistant edges. The final trajectories are created along the closest edges. This approach is efficient at navigating spaces with obstacles while optimizing trajectory planning [3].

For reliable path planning a UAV formation provides much more comprehensive data in regards to terrain and obstacles. Moreover, complex problems such as path planning and real-time obstacle avoidance are highly dimensional and might contain multiple local optima in which a deterministic algorithm might get stuck. This elevates the difficulty of correctly defining the objectives and constraints as explicit functions of decision variables. Stochastic Heuristic Algorithms (SHA) are a common alternative [4]. They introduce random noise in the optima finding process which is known to help in finding global optima. Examples include simple algorithms like Hill Climbing or ones inspired by natural processes like Genetic Algorithms, Simulated Annealing, etc.

Whilst a drone can make real-time decisions on its own – if coordination with other drones is desired – an efficient, reliable, and secure communication method is essential. Firstly, drones have to exchange flight and sensory data on a regular basis. While flight data such as position, and altitude are narrow in bandwidth, sensory and image data is costly Thus, for real-time sensory data exchange, proximity in a range of hundreds of meters helps enormously [5]. This naturally leads to the consideration of decentralized systems such as FANETs (Flying Ad-hoc Networks) [6]. Ad-hoc here means not relying on pre-existing infrastructure, rather each UAV acts as a node in the network. The simplicity of such networks enables UAVs to create and join networks on the fly. Once connected, drones can exchange sensory data and form a shared overview of the environment.

Advantages of autonomous drone control over manual control

Unlike human pilots who require rest and are vulnerable to fatigue and decisional errors, autonomous drones can operate continuously no matter the time of the day, maximizing operational time. A single drone operator may be needed to supervise entire fleets of drones, greatly increasing efficiency compared to manually controlling each drone. All of these drones could follow pre-computed routes with great precision and repeat them consistently, ensuring tasks are completed accurately across multiple operations. In this case, they are crucial for mapping by covering large areas with ease and providing high-resolution maps or 3D models. Another use case which benefits from this is precision agriculture, where crop health problems can be identified in the early stages. Autonomous spraying drones can be later used to selectively apply chemical agents based on the data gathered by imaging drones.

Autonomous drones can be used to access remote areas where manual operation is impractical or even impossible. Operating in areas with lots of obstacles, environmental threats, tight spaces or limited visibility is much easier for drones which use sensor data to navigate these spaces. Therefore, autonomous drones could perform industrial inspections for complicated construction sites, equipment inspections, and monitoring of pipelines, electricity power lines, bridges, wind turbines, and high-altitude antennas. In the case where the latency created by the distance between the operator and the drone is unacceptable, autonomous drones can be used to operate by themselves and transfer the data later. For example, the Mars Ingenuity Helicopter had to fly autonomously since the signals take around 5 - 20 minutes to be transmitted between Mars and Earth, real-time control being impossible in this case.

Other domains which make use of the advantages of autonomous drones include disaster management, environment monitoring, and delivery and logistics. Security patrols and search and rescue teams can use autonomous drones to scan large areas to find intruders or missing people. Drone data collection enables early detection of wildfires through continuous aerial surveillance. Some achieved an overall validation accuracy of 96.04% in recognizing fire images [7].

Future and challenges of autonomous drone control

Advancements in AI and Machine Learning allowed the integration of such algorithms into autonomous drones as Deep Q-learning [8] and Reinforcement Learning [9]. These algorithms allow the drones to adapt to various field conditions and take the right action in difficult or impossible situations to implement algorithmically. However, there are technical limitations to their application in real-life scenarios. Sophisticated AI and Machine Learning algorithms take up a significant amount of computational resources and hence require powerful processors, which are heavy and drain the battery fast. Drone researchers have to make a tradeoff between the computational capabilities and physical properties of the drone. As research continues and discoveries are made in the fields of physics, telecommunications, materials science, and computational technologies, drones will be able to be smarter, faster, and lighter. As the usage of drones in everyday activities becomes broader, businesses will try to occupy a large market share and will be willing to invest in drone research to optimize their operations and have a competitive edge over their competitors.

Other aspects that drone researchers have to take care of are issues with cybersecurity, data privacy, and technical safety. Since drones rely on wireless communication, the data that drones receive is prone to external factors. If the data is malformed, drones become a flying threat that may cause a collision with other objects, injuries, or start a fire. Real-life incidents, such as a collision of a drone with another aircraft [10], raise concerns about reliability. One of the most common attacks on drones is physical attacks on the drones, using crossbars, bows, or any heavy item. Companies like Amazon have patented several methods of safeguarding their drones, including object avoidance technologies and armored motors [11].

Another common way of hijacking drones is GPS spoofing. This way the hacker is able to send the drone to any desired location [12]. To combat this, researchers have developed numerous methods to counter GPS spoofing, including fast low-energy gyroscope measurements [13] and combining GPS with an Inertial Navigation System (INS) to maintain the drone's direction [14].

The future of drone development is largely defined by the legislative documents that will define the limitations of drone usage. Currently, drones are mainly used within the national borders. Drones will be able to travel across international space once two main problems are solved.

The first problem is the energetical limitations of drones. As of now, drones are powered by batteries, which have a limited amount of energy. To allow international flights, the drones will have to use renewable sources of energy, such as solar energy, or there needs to be massive progress in power-saving technologies.

The second problem is that every country has its own reserved frequencies. Hence, drones have to use allowed frequencies for communication. With every new country that the drone is able to fly in, more constraints of frequency are introduced, which might limit the total number of countries that the drones can fly in. It is also possible that a country might block frequencies for drones to restrict their usage in the given region [15].

Another highly anticipated application of drones is delivery. Companies like Amazon and Zipline are making a bet on drones since drones will reduce the delivery time for small and medium packages, are cheap, and require minimal human intervention and service [16, 17]. To allow this, Amazon, and other companies that are willing to offer drone delivery, would have to resolve numerous issues that have also been discussed in this article: security, battery capacity, privacy, and hijacking. All of these aspects are undergoing thorough research and will eventually lead to drone delivery services being available and affordable for the majority of customers. However, there still is a long way to go until drones replace traditional delivery models.

Conclusions

Drones are based on complex software components which are ought to coordinate together to perform optimally in different conditions. Sensor fusion, path planning, coordination, and communication are essential to drone operation and are the main areas of improvement and research. Autonomous drones are more promising from the point of view of practicality and rational resource usage. In contrast to manual control drones, autonomous drones can be used in extreme conditions such as high altitude, pressure, or even on other planets. As the technologies advance, governments and companies will be able to adapt more use cases that will optimize their processes. However, there are numerous challenges on the way to drone-driven businesses, such as cybersecurity issues, GPS precision, and technical limitations. The current progress tends to widespread usage of drones, partially or fully replacing such operations as delivery.

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