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Unmanned Aerial Vehicles for the Future: Classification, Challenges, and Opportunities

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***Abstract*—The world is moving very fast as Industry 4.0 has changed the way we live our daily lives. Researchers and strategists continue daily to explore technological innovations linked with artificial intelligence, machine learning, and robotics to support humans. The new technology no doubt will boost utilisation of resources and improve operations in diverse areas ranging from agriculture, health, military, oil and gas, transportation, big-box facilities, and fast-food services, thereby optimising processes and making life better and much more comfortable for humans. Unmanned aerial vehicle (UAV) has been identified as a special robotic system capable of meeting human needs if effectively programmed. This research is focused on the exposition of the diverse areas of application of UAV in the twenty-first century. Application of UAV in Agriculture, health, military, security, and others have been detailed. The challenges and future opportunities of UAVs have equally been identified. One of the major issues of concern is the endurance problem of UAV systems and issues on safety. Suggestions have been made on possible ways to address such issues.**

Keywords—unmanned aerial vehicle, Industry 4.0, robotics, machine learning, last-mile operations

I. Introduction

Autonomous vehicles, both ground and flying robots are becoming very popular in the 21st century. The need for UAVs or drones is becoming very necessary too as the world is greatly advancing and tasks are needed to be done timely and optimally. The traditional methods of lifting items, monitoring, and inspection using manned aerial vehicles are gradually reducing due to environmental pollution, cost of maintenance, and risk associated with manned operations.

UAVs are gradually taking over since they will never cause any form of pollution in the air, are a self-governing air vehicle, and the cost of operating it is quite affordable, unlike the manned vehicle. According to a report presented by the Association for unmanned vehicle systems international, it was estimated that by 2025, more than one hundred thousand jobs would be made available for citizens of the United States of America, which would have a great economic impact of eighty-two billion United States Dollars in the drone market commercially [1]. It was also reported in a Business Intelligence report that drones, especially for commercial, non-combatant, and general market is growing so fast at a multifarious rate of roughly nineteen percent. Furthermore, it was reported that about seven million modular UAVs are at present deployed or positioned in space for viable use in different sectors ranging from manufacturing to agriculture, health, and other sectors [2]. Delivery of useful items, especially medical-related ones, has been made possible with the help of UAVs. Other research has focused on UAVs have been reported elsewhere [3-9]. This research sets out to: give an exposition on the unmanned aerial vehicle, elucidate the different areas of application of UAVs and explore the current challenges associated with UAVs and the prospect of UAVs.

II. Brief Description of the Unmanned Aerial Vehicle

A UAV is a kind of aerial vehicle capable of autonomous flight with the absence of a pilot on board. The flight path of a UAV can be pre-programmed or controlled by a pilot using a radio transmitter from a ground station. UAVs are known to carry payloads and the type of payload being carried is a function of its size and weight. Generally, according to the authors in [10], there are two types of payload: a) Sensors; b) other payloads. The most commonly used sensor by the UAV is the camera [11]. The camera technology applied is as follows:

- RGB: This integrates three bands, and they are red, green, and blue.
- Multispectral: This integrates five bands, and they are red, green, blue, red-edge, and near-infrared.
- Hyperspectral: This is made up of about 2000 bands.
- Thermal: This forms heat zone images using infrared radiation operating at wavelengths of about 1400 nm.

The other sensors integrated on a UAV are the biological and meteorological sensors [12]. Other payloads that could be carried on a UAV include a spraying system, goods to be delivered, etc. Some UAVs in use include SenseFly, Parrot Sequoia, DJI Matrice 100 UAV, Skywalker X8 UAV, DJI inspire 2, H920 PLUS Yuneec, Parrot BEBOP 2FPV, Mavic Pro, Phantom 4 advanced, etc. UAVs can be classified based on four categories [13].

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A. Classification Based on Aerodynamic Features

Based on this category, the UAV can be classified into three types and the architectures are shown in Fig 1-4. The rotary-wing UAV is made up of the unmanned helicopter and Multicopter (tricopter, quadcopter, hexacopter, octocopter). The unmanned helicopter has high maneuverability and the capacity to carry an adequate payload. However, it is quite expensive and has high maintenance requirement. The multicopters on the other hand are lightweight, easy to launch, and are cost-effective. However, their payload capacity is limited, is susceptible to wind as a result of their light weight.

The fixed-wing UAV can travel long distances and has a high endurance capacity when compared to the rotary-wing counterparts. However, it is not easily manoeuvrable and because its take-off is horizontal, substantial space is required for easy take-off.

The Flapping wing UAV is a type of UAV that has the advantage of both horizontal take-off and vertical take-off and landing (VTOL). However, it is cost-intensive and technologically complex.

B. Classification Based on Level of Autonomy

According to the United States Department of Defense [14], the levels of autonomy for an autonomous system are of four types. The human-operated system is where a human operates all the operations of a UAV. The human-delegated system is a higher level of autonomy than the former where some level of autonomy is allowed.

Furthermore, the human supervised system involves the UAV being able to take various decisions but subject to the supervision of the human operator. The fully autonomous system is where the UAV is responsible for all its operations however the human operator can intervene in case of an emergency.

Fig 1. Unmanned Helicopter (*Source: [15]*)

Fig 2. Multicopter ((*Hexacopter*) (*Source: [16]*)

Fig 3. Fixed-wing UAV (*Source: [17]*)

Fig 4. Flapping wing UAV (*Source: [18]*)

C. Classification Based on Size and Weight

UAVs are classified according to ref. [19] as follows:

- Super-heavy: This is when the UAV exceeds 2000kg.
- Heavy: This is when the UAV weighs between 200kg and 2000kg.
- Medium: This is when the UAV weighs between 50kg and 200kg.
- Light: This is when the UAV weighs between 5kg and 50kg.
- Micro: This is when the UAV weighs less than 5kg.

D. Classification Based on Power Source

UAVs can be classified based on the type of fuels used for propulsion and they are: kerosene, battery cells, fuel cells and solar cells.

III. Methodology

A typical UAV developed by the authors would be briefly discussed in this section. It is a quadcopter built from readily available components and consists of the electronic speed controller (ESC), brushless motors, frame, lithium-polymer battery, flight controller, propeller, receiver, transmitter, etc. It is structured such that a brushless motor, that drives each propeller, is connected to an ESC which in turn receives signals from the flight controller powered by a battery. This UAV is controlled using a radio transmitter but could also be made fully autonomous by planning its flight path using a mission planner software. Its principle of operation is such that by varying the angular velocity of one or more motors relative to the others, the quadcopter carries out the roll, pitch, or yaw movements.

Before purchasing the quadcopter components, some calculations were performed to check for their compatibility. The amperage rating of the ESC was designed to be 50% greater than that of the electric motor. To withstand overheating, the lithium-polymer battery selected had a discharge current rate that was higher than the ESCs' amperage ratings. Also, the calculated thrust provided by the propellers was about twice the weight of the UAV hence lift was assured. The design of the developed UAV is shown in Fig. 5.

Fig 5. Design of the Developed UAV (*Source: [20]*)

IV. Areas of Application of The UAV

UAVs have a broad range of promising benefits and applications. Day by day, industries see the need to shift away from the traditional methods of monitoring, inspection, and delivery of products to the use of UAVs which assume fast delivery and a long range of travel. An overview of the areas of possible application and usability of UAVs has been detailed in this section.

A. Logistics Services

The popularity of drones in delivery services is immeasurable. Many organizations are currently integrating and fully adopting this significant technology in logistic services. In 2016, the popular online merchant business, Amazon was noted to have successfully delivered three hundred and ten (310) million products to customers globally [21]. It has been estimated that the number of online shoppers in Europe is probably between three hundred (300) and three forty (340) million [22]. The author in [23] further estimated the value to roughly four hundred and fifty (450) million. Last-mile delivery of products purchased online is fast on the increase and has become essential to growth in industries. Some of the companies currently in the logistics business using drones include Amazon, DHL, Shell, and others.

B. Food Services

Traditional methods of product delivery such as the use of a van for delivery are gradually fading and much more attention is given to universal delivery methods, one of these methods is the use of a drone, especially for the safety of the environment [24-25]. Many fast-food industries are advancing technologically for aggressive, easy, and faster delivery of products from source to destination. The authors in [26] developed a model for the planning of an effective supply chain in the era of Industry 4.0.

C. Security

Unmanned aerial vehicles are very useful in the surveillance and monitoring of facilities from third-party interference. They equally play a vital role in the area of protecting the environment and safeguarding species under any form of threat be it in the aquatic or terrestrial environment. As fully autonomous systems and infrastructure, highly equipped with cameras and sensors, UAVs are valuable for keeping humans out of any form of danger and security threat. South Africa is one of the countries effectively using autonomous aerial vehicles to protect rhinos from any form of danger from their target.

D. Healthcare

Portable or modular UAV systems are considered useful in this century for the prompt delivery of food, drugs, vaccines, medical supplies, detecting diseased patients as a way of mitigating the outbreak of deadly diseases such as the trending case of the coronavirus disease (COVID-19). They also support insufficiencies in response time during medical service response. The potential of utilizing UAVs to transport medical supplies, such as polymerase chain reaction (PCR) testing specimens, was emphasized by the authors in [27]. They proposed an efficient mathematical model which was able to plan routes for UAVs in a bid to reduce the transportation distance thus allowing for prompt delivery. Also, the authors in [28] proposed the application of a UAV for locating patients suffering from dementia.

E. Aerial Film, Photography, News Coverage, and Journalism

News coverage and Journalism are a difficult task which requires getting information from various sources based on happenings at different locations and this can be made easy using aerial coverage. The aerial film, news coverage, and photography service workers are undoubtedly the most popular commercial users of cameras for taking coverage of events. A shift from manual use of cameras for coverage of events to the use of flying robots or UAVs is prevalent nowadays. The procedural requirement for the operation of the UAV system is moderately low. Local and digital cameras can be attached to the UAV system and the process of mounting the camera is done with ease. The traditional methods used in the past are laborious and this paradigm shift to the use of UAVs is cost, time, and energy saving.

F. Aviation Industry

Due to the nature of the airline industry, inspection is very important for the safety of lives and properties. To achieve this, drones can be used. Adhering to safety compliance is very important in organizations and industries. This is far more important in the airline industry where stern regulatory standards must be maintained since the life of a multitude can be endangered if there is a system failure. The inspection must be done ahead of flight time. The manual method of conducting such inspection can be laborious and time-wasting, but the use of drone technology for routine inspection is easy and will facilitate the process. UAVs stationed for such inspections are fitted with cameras and allowed to cover a long range of distance to gather data and useful information for use ahead of flight time. This is far more economical and safer compared with the classical method of inspection.

G. Telecommunication

Service reliability is very important in the telecommunication sector. Masts positioned at strategic locations must be inspected regularly to ensure service consistency. Traditionally, staff of telecommunication sectors usually mount on the Masts for very risky inspection and the use of the manned aerial vehicle as alternative means of inspection is very expensive. The best way to inspect such facilities is the use of UAVs. This method is safe, fast, reliably, and environmentally friendly.

H. Oil and Gas Industry

The UAV is particularly important for security, monitoring, and inspection in the oil and gas sector. The location of defects in a pipeline is possible at the internal and external levels. Much research has been conducted to focus on the location of defects in the pipeline at internal surfaces where maps and lines are drawn for easy navigation of robots inside a pipeline [29-30]. The authors in [31] believed that such systems are based on inertial measurement units and odometry to effectively build and plan an effective path for easy location of pipes via maps. In research presented by Zsedrovits et al [32], an onboard UAV optical system was presented, the system is built and prepared for obstacle avoidance and the visual detection range varies which is subject to the objects detected. A similar idea was presented by Holz et al [33] where obstacle detection and avoidance were developed with a visual system and other important parts.

I. Education Sector

UAVs will add great value to teaching and students learning in this era of industry 4.0. The ever-growing UAV technology will be very useful for educating students and for research purposes. For practical demonstration, students at primary, secondary, and tertiary levels can use drones to learn by handling real-life problems and challenges with drones or UAV technology. Equally, facilitators, lecturers, or teachers can impact their students positively using drone technology especially for STEM (science, technology engineering, and mathematics) activities and they can learn experiences like the design and development of drones, the navigational pattern of drones, path planning algorithms, how best to handle endurance problems and others.

J. Traffic Monitoring

Research on traffic data focused on the behavior of drivers on busy roads, the navigational pattern of vehicles can be captured using the UAVs. Research on related areas of traffic for monitoring and inspections on highways, surveillance, handling traffic congestions, monitoring the possibility of accidents and causes have been discussed [3][34-36].

K. Agriculture

In this era of Agriculture 4.0, efforts are being made by farmers to increase food production and optimize the cost of procuring materials such as fertilizers, herbicides, pesticides, etc. by employing UAVs for precision agriculture. UAVs are being equipped with cameras (RGB, multispectral, hyperspectral, or thermal) for acquiring aerial images to calculate some vegetation indices which could help a farmer make relevant decisions. These are decisions concerning pest and diseases [37] weed detection [20], nutrient deficiencies [38], water stress [39], irrigation [40], etc. affecting crop productivity. UAVs could also be employed for spraying agrochemicals and are seen to be more advantageous over manual spraying as the latter is detrimental to human health. In agreement with the author in [10][41], deploying UAVs with both aerial monitoring (using deep learning algorithms) and spraying capabilities will further improve the effective and efficient use of agrochemical products. Also combining the proposed deep learning algorithms with optimization techniques, according to the authors in [42], would enhance real-time operations using the UAV.

L. Conservation of Ecosystem

In recent times, the number of endangered species and loss of biodiversity is seemingly on the increase hence effective monitoring of these habitats and the wellbeing of wildlife is imperative. UAVs, in the field of ecosystem conservation, are being used to monitor/assess whale health [43], habitats distribution, movement of wildlife, biodiversity [44], invasive plant species[45], anti-poaching function[46], using various camera sensors. The authors in [47] were able to monitor stream channel dynamics, identify types and loss of habitats, estimate extinction risk utilizing image data obtained by a UAV. Also, in [48], the authors proposed a UAV integrated with a thermal and RGB camera for wildlife tracking. The recorded images were applied post-flight on a detection algorithm.

M. Disaster Relief

Studies [49] have predicted that in years to come, there would be a rise in disasters caused by weather-related events. After the occurrence of a disaster, there may be delays in getting relief across to the victims due to some circumstances including blocked roads. Hence, the use of UAVs could serve as a potential mode of transportation to locate the victims and also deliver useful items to support them. UAVs are also used to carry out the risk assessment, mapping, and planning for the disaster-affected regions [50].

N. Emergency Response

According to the United Nations, the world population is estimated to be about 9.8million by 2050 and this implies that there would be a high influx of people into the urban areas and hence the need for the deployment of UAVs in the area of traffic management and emergency response. In this area, UAVs function to detect accident scenes and give feedback to the first responders' team, detect traffic congestions and fire-outbreaks. The authors in [51] applied deep learning (DL) detection algorithm on a UAV for traffic management and were able to achieve a detection accuracy of 95%. In further work, they developed the EmergencyNet convolutional neural network model for aerial image classification to be carried out onboard on a UAV for emergency response applications [52].

O. Marine

There has been a challenge in obtaining sufficient information about the distribution and behavior of marine vertebrates due to their inaccessible habitats and erratic movement patterns [53]. UAVs are employed in this domain as they are a reliable source for collecting aerial images of these animals. They are also being applied in the inspection of oil and sewage spills from ships [54], maritime search and rescue [55], etc. The UAV was proposed by the author in [56] to collect data on the abundance of the marine megafauna and also monitor its behavior. They observed some occupancy patterns and also proved that UAVs can obtain the distribution and abundance of marine megafaunas in shallow-water habitats.

P. Military Operations

Modular UAVs such as predator and global hawk are designed for surveillance, air-to-air combat, and reconnaissance of ground objects. They minimize the loss of human lives in the military population, defeat and neutralize the enemy's UAV, decide the target for attack, etc [57]. The need to utilize autonomous robots such as UAVs for military operations was highlighted in [58]. Also, the authors in [59] described the advantages of employing UAVs for military purposes.

Q. Mining

Difficulty in accessing remote areas such as vertical cliffs, unstable volcanic areas, mountainous areas, and unsafe topography creates the niche for the use of UAVs in mining and exploration. They can be applied for aerial surveys, real-time field/3D mapping, search and rescue missions, explosive package delivery, monitoring and inspection. The authors in [60] employed a UAV for the aerial survey of an abandoned mine in South Africa. Similarly, in [61], a UAV was designed and developed for underground mine surveys.

R. Construction and Urban Planning

Over the years, UAVs have been introduced into construction projects to enhance productivity, minimize cost and time. UAVs can be designed to capture data around construction sites [62], bridge inspection [63] thus giving adequate information of the progress of work on sight. They can also be employed to survey and map out cities effectively. This is made possible when the architecture of the metropolitan is well understood and also made easy by defining a path planning for easy navigation of the UAV.

V. Challenges and Future Opportunities

This study has exposed the vast and broad range of applications of UAVs ranging from logistics services to delivery of food, traffic monitoring, security, news coverage, and others. The paradigm shift from the use of traditional techniques of delivery services, monitoring, and surveillance, information gathering in organizations can be applied to a range of diverse industries. Outline of the areas of possible applications and usability of UAVs have been discussed. There are still many more areas of applications not discussed in this paper, but the major fields of application of UAVs have been explored. However, it is important to examine the challenges and future opportunities of UAVs with a focus on the logistics industry. The focus is centered on logistics operation and surveillance because almost every product and service-based industries require one form of distance operation or another at inbound and outbound locations. There are challenges associated with the UAVs such as the safety of humans especially in cases where there is a failure of the UAV system as the crash landing can be disastrous; endurance problem of UAV is another issue, if the sustainability of the battery life can be handled then the UAV system can last longer on air; most UAV systems are developed in the modular form which affects the capacity of load the UAV system can carry; the issue of unclear government regulations and also the fact that the UAV is affected by unfavorable weather conditions. Other noticeable and future opportunities of the UAV system in pick and place operations or last-mile delivery and security monitoring and inspection are unveiled.

A. UAV for Last-mile Operations

As earlier discussed, logistic operations in top companies like Amazon, DHL, Shell, and others have made the delivery process much easier. The use of unmanned aerial vehicles to deliver items have so many benefits ranging from total reduction in the cost of delivery, a great advantage of maintaining the cost of manning the system since there is no pilot or aerial cost as the system is programmed to function autonomously, a bottleneck of any kind is equally eliminated as the system can freely navigate from source to destination without any form of traffic congestion. The most important part is the tendency of delivering items timely as customers will never experience any form of missed deliveries [64], especially from source (point of delivery or factory) to destination (customers end). Optimizing delivery time and efficiency of the delivery process is a huge gap to fill in the use of UAV systems for effective delivery [65-70]. Unmanned aerial vehicles have great opportunities in the future which will go a long way in favoring industries implementing drone operations and customers receiving in last-mile operations. This is possible by using android devices as its core onboard processing unit. Navigation is equally faster using google maps to action navigation and delivery process from source to destinations.

B. UAV for Security Monitoring, Inspection, and Information Gathering

Activities at in-bound, in-process and out-bound locations, as well as infrastructure, must be properly monitored from third-party interference. Security and safety of facilities can be ensured using the UAVs which provide proper surveillance. In the oil and gas sector, pipeline infrastructure for moving solid, liquid, and gaseous materials from one station to another must be adequately protected and can be fully monitored using UAVs both in the onshore and offshore environment. Also, warehouses in big-box stores and retail facilities can be monitored using UAVs. In terms of monitoring, UAVs can equally be stationed to monitor the safety of a warehouse and the loading and offloading of goods at inbound and outbound locations. Maintenance activities during road projects can be tracked and monitored using flying robots. Activities in dangerous, hazardous, and hard-to-reach areas or confined spaces can be monitored during minor repair or turnaround maintenance. Keeping perfect records of operations in a hazardous environment in oil and gas and mining sites can be achieved using modular UAVs. For the future, synchronization of multiple UAVs and also UAVs with ground robots in the complex domain is possible to support responsibilities and operations in industrial, manufacturing, oil, and gas domain to monitor task such as cleaning operation in confined space, offshore operations, locating missing personnel or employees, tracking and monitoring of asset and many other complex operations.

VI. Conclusion

Recent research studies have revealed the continuous progress achieved in utilizing UAVs for a range of applications. This study has succeeded in showcasing a brief description of UAVs and their applications in diverse fields ranging from agriculture, security, oil, and gas to urban planning among many others. One of the major challenges of implementing UAV is the endurance problem, this has to do with the sustainability of the battery life of a UAV system. If endurance issues can be handled, then the UAV system can last longer in air during operation. Another puzzle is the synchronization or coordination of multiple UAVs. As the number of UAVs deployed on a corporate mission increases, it becomes very difficult to coordinate and control the dynamic interaction of such multiple robots without collision. It is also important for the government and corporate bodies to look into operational guidelines, policies, and regulations to follow so as to ensure the safe use of UAVs. Finally, in this era of industry 4.0, most organizations are making prodigious efforts to embrace the current technology, it is important to consider enhanced technologies for effective UAV path planning, UAV development strategies, UAV control strategies, deployment models, and techniques. Future research will focus on synchronization between UAV and UGV (Unmanned Ground Vehicles) in a complex domain.

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