CONSIDERATIONS FOR THE NEXT GENERATION OF DRONE DELIVERY SYSTEMS

Imoleayo S. Asiwaju[1]., Abiodun B Yusuf[2]

1. Lulea University of Technology 2. Leeds Beckett University

imoasi-0@student.ltu.se, a.b.yusuf@leedsbeckett.ac.uk

Abstract

The development of Unmanned Aerial Vehicles (UAVs), also known as drones, revolutionised many sectors such as agriculture, transportation and the military. In this technological era, drone technology has experienced a significant increase in its use. Artificial intelligence (AI), as an emergent field, has proven to unlock and improve many application areas for drone usage. However, many specialised drone usage often requires unique features for effective and efficient application. This study provides an overview and a different feature comparative review of a " conventional" drone system to an AI-enabled drone system, specifically for delivery and logistics applications. Intelligence providing features such as computer vision, speech synthesis, face recognition, and wireless charging are improvements for better performance of the delivery drone system. However, the research also highlighted some limitations, different technology scopes, and a discussion on possible trends for advances in drone technology.

Introduction

Developing Unmanned Aerial Vehicles (UAV) has been a promising field. It has attracted different sectors ranging from e-commerce, manufacturing, entertainment, and agriculture, among others, which have been an area of research interest since its commercialisation in 2006 (Ivy Wigmore, 2013). Moreover, the utility and flexibility of UAVs in different sectors, such as in logistics, has been on the increase. Consequently, UAVs have significantly reduced the cost and time of package delivery in the logistics industry. This benefit has been because " drones" (as they are colloquially known) are cheaper to maintain than traditional delivery trucks, and the labour cost requires less human input, thus saving energy (Dorling *et al.*, 2017).
Drone delivery has proven helpful in various industries; in 2016, Amazon Prime Air made its first drone delivery in the city of Cambridge, carrying an item of less than 2.6kg covering a distance of about 10 miles in less than 10 minutes (Amazon, 2014). Amazon Technologies obtained a patent for a multi-level fulfilment centre for UAVs to help land and deploy these drones in a dense urban setting (Shenk S and Westerhaus, 2013).
Drones for delivery systems comprise three major technological innovations – data processing, autonomy and boundless mobility (Kellermann, Biehle and Fischer, 2020). However, despite the incredible capabilities of UAVs, (Lahmeri, Kishk and Alouini, 2020) highlighted some possible limitations of UAVs for delivery systems, such as limited battery capacity and low computational power.
With a focus on considering the limitations of drones in delivery applications, this work discusses how the implementation of machine learning and artificial intelligence, like computer vision, could further enhance fully autonomous UAVs for delivery purposes. In addition, this study concentrates on developing a concept of intelligence in delivery drone systems and proposes an artificial intelligence system that can improve delivery drones. The scope of the report is as follows:

- A focus on delivery drone development and the technologies used – highlighting the implementations of artificial intelligence systems like speech synthesis, computer vision and face recognition.
- The outline of an autonomous drone delivery system for the e-commerce industry is provided with the context of a customer 'packages' delivery system.

The rest of this paper is organised as follows: Section II gives the overview of drone systems and their uses, Section III describes the drone delivery system' domain analysis, and Section IV explains the structure of the drone, while Section V reviews some proposed intelligent features for the drone delivery system, and Section VI gives drawbacks of the proposed features, and finally Section VII gives conclusion and possible recommendations.

Overview of the Drone system

A UAV, popularly known as a drone, is a type of robot that flies and does not require any pilot on-board to operate; it is a pilotless aircraft that can either be remotely controlled or fully autonomous (Rojas Viloria *et al.*, 2021). Initially, the word "Drone" was generally known as the only pilotless aircraft used in the military. However, in 1960, the definition took another shape and expanded, and we have acronyms like UAV, remote piloted vehicle (RPV).

UAV can be broadly categorised into two:

i. Fully autonomous aircraft
ii. Remotely piloted aircraft.

History suggests that in the mid-1800s, the first drone was developed and used for photography, security, and safety of the environment. (Alkobi, 2019). Today, drones serve multiple functions and are used for different purposes. Figure 1 shows the progression in the usage of drones over the last few decades.

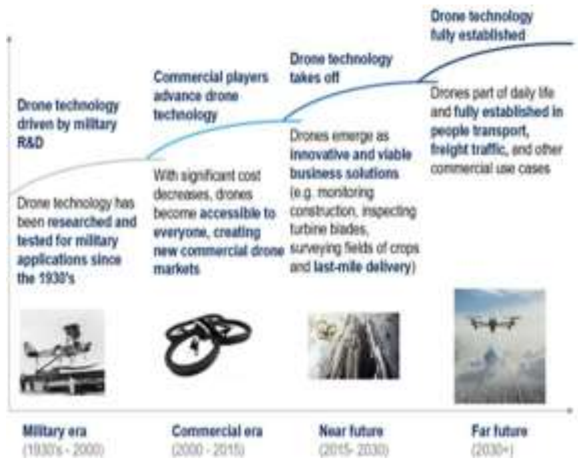


Figure 1 - A history and progression about the development and usage of drones (Sifton, 2012).

Considering drones for delivery purposes, several companies already exist within this space. **Retail companies** started exploring the possibilities of utilising drone technologies to deliver customers' goods, reducing cost and energy footprint. **Amazon**: Amazon, one of the biggest online retailers, is the most public and advanced in experimenting with drones for item delivery. Amazon launched their drone delivery offering with "Amazon Air Prime" and incorporated, "bring it to me" features to capture customers' locations using GPS data obtained from phones and IoT devices (amazon.com, 2021). **Google**: Google started a project called "Project Wing", which is run by a subdivision in Google called the Google X, researching the usage of drones for packet delivery (Chappell, 2019). Logistics Companies like UPS, DHL and FedEx also join in the race of implementing drone technologies for packet delivery (Kellermann, Biehle and Fischer, 2020).

Domain Analysis

The domain model considered in this study improves the intelligence and robotics features of the overall drone system. However, the general domain of interest for analysing our use case UAV system, the drone delivery system, involves implementing computer vision, speech intelligence and translation, and chatbot technology to process speech and have conversations using a natural language. For comparison, a drone system designed with no features suffices. Moreover, several variants of the delivery drone system based on domain-driven design serve as an incremental design of the conventional baseline system. Simply adding a single feature or multiple features to the baseline implementation will undoubtedly improve the system's utility. This notion of variants implies that each element or service enablement added to a conventional drone system can be considered a standalone drone delivery system and serve a business functional requirement.

Functional Requirements to note:

1. Shipping is the primary reason for the business and is principal to the overall solution architecture. Every other domain is helping to facilitate this and make shipping better.
2. Drone management: The intelligence features are introduced, with functionalities closely related to drone management. Such as predictive analysis, face recognition with computer vision, self-diagnosis for maintenance, wireless charging, speech intelligence for a chatbot to enable communication with customers, and geolocation tracking.
3. Estimated Time of Arrival (ETA) analysis provides an item's estimated pickup and delivery time.
4. Emergency alert to prompt the server room in case of any emergency occurrence to the drone should send current geolocation data, with a video clip of drone flight to determine events.
5. User feedback, accounts, invoicing, and call centre is subdomains that support the core business

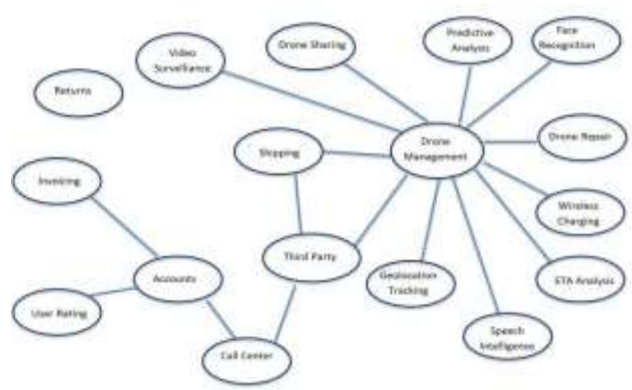


Figure 2 - Key features in a drone delivery system implementation

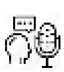
Structure of the UAV

This section presents a brief discussion on the delivery drone's internal structure, which involves the advancement of a regular drone with the proposed intelligent features.

1. The Flight Controller: This is the central part of the UAV system. It consists of the proportional–integral–derivative (PID) controller and maintains the balance of the UAV, controlling all received signals. In addition, the Nonlinear PID (NLPID) proposed by (Najm and Ibraheem, 2019) can help stabilise all motions of an autonomous UAV.
2. Sensors: Various sensors will manipulate and control the different ' 'system's states, such as the amplitude, velocity and intelligent features described in the next section.
3. Flight code: This is the code control logic and the model development of the simulation using the model-based design and the flight code consists of the flight control software, memory management, computer vision code, Bluetooth I/F, Sensor I/F, battery management, Motor, LEDs, Internal messaging, speech synthesis.

Some Proposed Intelligence Features

As seen in Figure 2, key features are essential to get optimal operational performance for an intelligent drone delivery system. The table below highlights some proposed important features critical for the drone performance and functionality:

Features	**Description**	**Possible Challenges and Potential Solutions**
 **Computer Vision**	To send visual data of its location and help track objects while working on self-navigation, detect and dodge obstacles to avoid collision and avoid potential harmful things or danger. (Akbari *et al.*, 2021). The computer vision features can detect different objects using stereo odometry, as seen in (Shi and Tomasi, 1993). The algorithm can be used to capture essential elements in the environment to avoid obstacles and collisions during flight waypoints. It is also important to note that UAVs do not obtain any data from the environment during the flight mission but only use the computer vision algorithm to avoid collisions and obstacles. (Kanellakis and Nikolakopoulos, 2017) Pproposed optic flow algorithm fused with Inertial Measurement Unit (IMU) using an Extended Kalman Filter (EKF) incorporated with a nonlinear controller for 3D navigation, Linear Quadratic Gaussian/Loop Transfer Recovery (LQR-LTR) control method can then be used to stabilise the system for considering a set point to be capture.	The major challenge is data privacy and security and can be resolved by limiting collected data when the UAV arrives at its destination alone. Another challenge is the computational time and resources involved in computing the algorithms.
 **Speech Synthesis**	The implementation of speech synthesis and translations which help in the conversion from speech to text and help drones in interpreting and communicating with customers (Contreras, Ayala and Cruz, 2020). The system is configured to collect and reproduce input voice control instructions using speech recognition algorithms - Kaldi pitch which is a high modification of the getf0 (RAPT) algorithm (Ghahremani *et al.*, 2014) using the Keele database. The speech synthesis will be helpful, especially for visually impaired users, as there can be communication between the system and the owner of the goods, solving the communication bridge between the two parties.	Speech synthesis may present a significant challenge due to the limited dataset to be implemented in the UAV. A solution will require different datasets for different countries and ethnicities. In addition, the processing of the speech synthesiser will be done at the edge computer, which will consume a lot of energy.

Face Recognition	Though this is a subset of Computer Vision, it is an essential feature of an intelligent system. Determine goods ownership and capture verification images of the receiver in case of theft or accident. For privacy, facial recognition data will not be implemented during flight and only after the UAV arrives at the destination. The emergence of 5G/6G networks and edge computing help in processing real-time streaming video to capture and detect the owner of the goods, which avoids storing video data. An accurate algorithm which is the Local Binary Pattern Histogram (LBPH) method, can be implemented for face recognition using the Open Source Computer Vision (OpenCV) (Bradski, 2018). The algorithm can recognise the goods' owner and subsequently trigger access protocols through its account. This process can be achieved using a QR scanning code stored in its account in a mobile application. The goal is to make sure video streaming data is not stored but processed in real-time for the sake of data privacy.	The analysis will be a significant issue as this will consume much computation resources on the UAV system, which has limited battery life.
GPS Tracking	This feature will track the drone's present location and support the fleet management protocols in emergency and retrieval. Furthermore, the UAV will be equipped with a Global Positioning System and Inertial Navigation System sensors for the position, angular behaviour, and orientation in space for the GPS tracking. As a result of the inaccuracy and undesirable performance of GPS signals due to noise, bad weather conditions (García Carrillo *et al.*, 2012), proposes a vision-based autonomous positioning and navigation using stereo vision and inertial navigation system in the development of the drone. In addition, the drone should have an ultrasonic sensor and an atmospheric pressure sensor for determining the ' 'drone's altitude. These stereo vision and inertial sensors can then be used with the vision-based measurement in a Kalman filter to provide precise and accurate ' 'drone's position at every given time. Furthermore, the simultaneous localisation and mapping algorithm (SLAM) included a monocular vision system and a nonlinear sigmoid based controller to help UAVs navigate the pathway.	One major challenge is the UAV system adapting to dynamic environments as this will involve different computations and consume system energy and resources. In addition, UAVs are flying vehicles and cannot stop operating in the sky due to uncertainty in the state estimation. This can lead to a crash of the UAV, so there is a need for accuracy in developing the different algorithms employed.
Wireless Charging	One of the significant issues with drones is the battery life. Wireless charging can be implemented on drones to increase their battery life to mitigate this challenge. However, the commonly used charging technique for UAV is battery swapping, and this method possesses many drawbacks for autonomous drones with critical missions. Therefore, different innovative approaches like Gust Soaring, laser beaming, battery dumping have been proposed to help solve the battery life problem of UAVs. (Deittert *et al.*, 2009; Malaver *et al.*, 2015; Richardson, 2015). However, wireless Power Transfer (WPT) for UAVs will help solve battery changes and remove the human interface in an autonomous drone. WPT can be classified into two categories based on the transmission range: • Near Field Transmission (NFT), Capacitive Resonant Power Transfer (CPT), Inductive Power Transfer (IPT), which are for short-range transmission, and IPT is most suitable because of its high tolerance level, transfer capability and design compatibility with various UAVs • Laser-based charging and Microwave Power Transmission (MPT) can provide for a far-afield line of sight transmission. Laser-based power transmission is based on Distributed Laser Charging (DLC) technology and can transfer up to 2Watts within a range of 5meters.	The wireless charging system is prone to jamming, safety, and software attacks, and there is a need to safeguard the system. Also, with the rise in the usage of UAVs, there is a need for handling a large number of UAVs, avoiding charging conflicts and further efficiently managing UAV batteries for better performance

Weather Sensors	To enable drones to get data to forecast the weather in emergency weather and activate emergency landing or the "take back home" features.	

Drawbacks of the proposed system

Disturbance, Dangers and Ethics

Implementing delivery drones in e-commerce means adopting more drones in the sky, which has its drawback. The number of drones in the sky, also called " Angels in the sky" (TCK, 2019), will increase numerically. In return, it could pose a danger to birds, the surrounding ecosystem, and even humans in the event of a collision. An increase in drones can lead to congestion in the airspace, which can cause traffic which may lead to delays in flights or collisions with other entities in the airspace, as seen in Figure 3. The noise produced when flying a drone is another major problem of drones. This noise can drive birds away from their nest, leading to abandoning eggs and chicks (Wilson, 2014). Furthermore, some birds can intentionally attack drones, leading to a collision that the ' 'drone's collision detection cannot avoid. Therefore, due consideration should be given towards the wider adoption and use of drones due to the potential impacts to the environment as a whole, and especially birds, where such technology could be dangerous for their survival.

Figure 3 - A Drone crash with an aeroplane in Mexico (A Drone Hit A Boeing 737 In Mexico, 2018)

Delivering drones with cameras for navigation purposes may be considered unethical because it has the potential for intruding on people's privacy. However, (Wilson 2014) stated that fully autonomous drones would not be regarded as breaking duty ethics and invading privacy. Therefore, this aspect of intelligent drone delivery system implementations must also be given due consideration, and possible safeguards be put in place to ensure these concerns are mitigated to the greatest extent possible.

Conclusion and Future Consideration

Drone delivery will eventually be the next wave of the e-commerce industry and will be successful in the last mile delivery with better performance such as:

i. Convenience
ii. Cheaper Cost
iii. Fast delivery
iv. Eco friendly

Drone delivery, which many industries have implemented, is feasible and is the new drive in the e-commerce industry. Finally, in examining how intelligent features can be implemented to drone delivery for better performance, to solve some of the issues rising against the use of drones in the e-commerce industries, some future considerations can be followed, namely:

1. Drone approved by the FAA, tested to be less noisy, with robust failure redundancies, should be allowed for delivery purposes.
2. There should be hardcoded minimum and maximum flying altitude for these drones, and they should only be permitted to fly in public areas to avoid intruding on the privacy of others, and they should be fully autonomous
3. Establish social contract theory for moral rules to govern the relationship among citizens to protect 'citizens' right to privacy and safety.

The future of drones as proposed by (*Urban Air Mobility (UAM) | EASA*, 2020) is Urban Air Mobility (UAM) which is expected in Europe and regulated by the European Union Aviation Safety Agency (EASA) to ensure the airworthiness operational and pilot licencing and the integration of various airspace.

Acknowledgements

This work was funded under the Erasmus Mundus Master program, Green networking and cloud computing.

References

A Drone Hit A Boeing 737 In Mexico (2018). Available at: https://www.aerotime.aero/22945-drone-hit-boeing-737-mexico (Accessed: 8 April 2021).

Akbari, Y. et al. (2021) 'Applications, databases and open computer vision research from drone videos and images: a survey', Artificial Intelligence Review, pp. 1–52. doi: 10.1007/s10462-020-09943-1.

Alkobi, J. (2019) The Evolution of Drones: From Military to Hobby & Commercial, January 15. Available at: https://percepto.co/the-evolution-of-drones-from-military-to-hobby-commercial/ (Accessed: 12 March 2021).

amazon.com (2021) Amazon.com: Prime Air, Amazon. Available at: https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011 (Accessed: 23 November 2021).

Amazon (2014) Amazon Prime Air, Amazon.com. Available at: http://www.amazon.com/b?node=8037720011 (Accessed: 22 March 2021).

Bradski, G. (2018) Face Recognition with OpenCV — OpenCV 2.4.13.7 documentation. Available at: https://docs.opencv.org/2.4.13.7/modules/contrib/doc/facerec/facerec_tutorial.html#face-recognition (Accessed: 5 December 2021).

Chappell, B. (2019) Wing Drone Delivery Company Gets FAA OK To Operate As An Airline : NPR. Available at: https://www.npr.org/2019/04/23/716360818/faa-certifies-googles-wing-drone-delivery-company-to-operate-as-an-airline (Accessed: 23 November 2021).

Contreras, R., Ayala, A. and Cruz, F. (2020) 'Unmanned aerial vehicle control through domain-based automatic speech recognition', Computers, 9(3), pp. 1–15. doi: 10.3390/computers9030075.

Deittert, M. et al. (2009) 'Engineless unmanned aerial vehicle propulsion by dynamic soaring', Journal of Guidance, Control, and Dynamics, 32(5), pp. 1446–1457. doi: 10.2514/1.43270.

Dorling, K. et al. (2017) 'Vehicle Routing Problems for Drone Delivery', IEEE Transactions on Systems, Man, and Cybernetics: Systems, 47(1), pp. 70–85. doi: 10.1109/TSMC.2016.2582745.

García Carrillo, L. R. et al. (2012) 'Combining stereo vision and inertial navigation system for a quad-rotor UAV', Journal of Intelligent and Robotic Systems: Theory and Applications, 65(1–4), pp. 373–387. doi: 10.1007/S10846-011-9571-7.

Ghahremani, P. et al. (2014) 'A pitch extraction algorithm tuned for automatic speech recognition', ICASSP, IEEE International Conference on Acoustics, Speech and Signal Processing - Proceedings, pp. 2494–2498. doi: 10.1109/ICASSP.2014.6854049.

Ivy Wigmore (2013) What is personal drone? - Definition from WhatIs.com. Available at: https://whatis.techtarget.com/definition/personal-drone (Accessed: 12 March 2021).

Kanellakis, C. and Nikolakopoulos, G. (2017) 'Survey on Computer Vision for UAVs: Current Developments and Trends', Journal of Intelligent and Robotic Systems: Theory and Applications, 87(1), pp. 141–168. doi: 10.1007/s10846-017-0483-z.

Kellermann, R., Biehle, T. and Fischer, L. (2020) 'Drones for parcel and passenger transportation: A literature review', Transportation Research Interdisciplinary Perspectives, 4, p. 100088. doi: 10.1016/j.trip.2019.100088.

Lahmeri, M.-A., Kishk, M. A. and Alouini, M.-S. (2020) Artificial Intelligence for UAV-enabled Wireless Networks: A Survey. Available at: http://arxiv.org/abs/2009.11522 (Accessed: 22 March 2021).

Malaver, A. et al. (2015) 'Development and integration of a solar powered unmanned aerial vehicle and a wireless sensor network to monitor greenhouse gases', Sensors (Switzerland), 15(2), pp. 4072–4096. doi: 10.3390/s150204072.

Najm, A. A. and Ibraheem, I. K. (2019) 'Nonlinear PID controller design for a 6-DOF UAV quadrotor system', Engineering Science and Technology, an International Journal, 22(4), pp. 1087–1097. doi: 10.1016/j.jestch.2019.02.005.

Richardson, P. L. (2015) 'Upwind dynamic soaring of albatrosses and UAVs', Progress in Oceanography, 130, pp. 146–156. doi: 10.1016/j.pocean.2014.11.002.

Rojas Viloria, D. et al. (2021) 'Unmanned aerial vehicles/drones in vehicle routing problems: a literature review', International Transactions in Operational Research, 28(4), pp. 1626–1657. doi: 10.1111/itor.12783.

Shenk S, J. and Westerhaus, M. O. (2013) Patent Images. Available at: publication/uuid/4771DF08-6D9D-4DFC-913A-2D965A0016AD (Accessed: 22 March 2021).

Shi, J. and Tomasi, C. (1994) 'Good features to track', Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition, pp. 593–600. doi: 10.1109/cvpr.1994.323794.

Sifton, J. (2012) A Brief History of Drones | The Nation, The Nation. Available at: https://www.thenation.com/article/brief-history-drones/ (Accessed: 27 March 2021).

TCK (2019) Should we implement delivery drones? | Professional Responsibilities Of The Engineer, Ethics Forge. Available at: https://www.ethicsforge.cc/angels-in-the-sky/ (Accessed: 23 November 2021).

Urban Air Mobility (UAM) | EASA (2020). Available at: https://www.easa.europa.eu/domains/urban-air-mobility-uam (Accessed: 4 December 2021).

Wilson, R. L. (2014) Ethical issues with use of Drone aircraft, 2014 IEEE International Symposium on Ethics in Science, Technology and Engineering, ETHICS 2014. doi: 10.1109/ETHICS.2014.6893424.