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Autonomous drone control within a Wi-Fi network

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Abstract*—Over the past ten years there has been a substantial growth in the expenditure of quadcopter drones. Whilst the greatest expense remains with the military, drones are finding increased use in commercial applications such as construction, agriculture, oil and gas and cinematography. However, a major shortcoming of the quadcopter drone is its limited flight time of 30 minutes. Recharging and replacing batteries, significantly impedes and interrupts the desired drone mission. A possible solution is to deploy a number of drones connected and communicating over a network enabling greater are coverage for the same flight time. This paper describes the development of a multiple drone network constructed from commercially available drones. A single autonomous drone is initially constructed which is able to follow a predefined flight plan. The single autonomous drone is developed to enable the formation of a network with other similarly constructed autonomous drones. Flight command codes are able to be transmitted between drones to instruct the receiving drone to fly a particular flight path. Results presented confirm the performance of the controlled flightpath of the autonomous drone and the ability to pass flight command codes between drones across the network.

I. INTRODUCTION

Since 2013 the popularity and growth in expenditure of drones, also known as UAVs, (Unmanned Aerial Vehicles) has seen a considerable increase. The Teal Group estimate a worldwide increase in expenditure from $5.2 billion dollars in 2013 to $11.6 billion dollars by 2023 [1]. It is expected that military applications will continue to account for 70% of drone expenditure, with drone hobbyists (consumer applications) accounting for 17%, and civil and commercial applications accounting for the remaining 13% [2]. The hobbyist has a vast range of drones to choose from depending upon requirements and cost. Some of the more popular manufacturers include Parrot with the AR2 drone, DJI with the Phantom drone and 3DR with the Iris drone [3] [4] [5]. The top one hundred drone manufacturers is published on a number of platforms [6]. The number of drone hobbyists has also grown substantially with the FAA (Federal Aviation Administration) reporting an excess of one million drone owners in the US [7]. However, it is within civil and commercial applications where the greatest growth is predicted. Applications within the construction industry, including building surveys and inspections account for 50% of commercial expenditure [8]. Other growth applications in the commercial and civil sector include agriculture, offshore oil and gas, policing, border protection, mining, and cinematography [2].

The quadcopter drone has four independent rotors driven by four electric motors providing excellent stability, vertical take-off and landing capability, is able to hover, and is generally relatively straightforward to fly and control. In particular, it is the drone's ability to hover, which enables it to partake in such missions as surveillance, search and rescue, and aerial photography [9] [10] [11]. However, the efficient completion of such missions is significantly compromised by the inability of the drone to remain in the air for significant periods of time [12] [13]. Although improvements in battery technology are enhancing the lifetime of drone batteries and enabling longer flight times, currently, the maximum drone flight time is limited to approximately thirty minutes [14] [15]. This shortcoming of the single drone solution has seen the emergence of multiple drone systems. Drones are connected and communicate over a network enabling greater area coverage for the same flight time [16]. The multiple drone solution whilst improving the performance of the single drone yields a number of technological challenges including communication and networking, co-ordination, and sensing [17].

II. METHODOLOGY

A. The autonomous flying drone hardware configuration

French manufacturer Parrot released the first commercially available 'out of the box' drone, the 'AR drone' in 2010 [18]. An enhanced version of the AR drone, the 'AR2 drone' was released in 2012. The AR2 drone benefits from enhancements to on-board sensors and equipment and has been used extensively in research projects and is the drone of choice for this study [19] [20].

The Parrot AR2 drone is controlled by a platform such as a smartphone or a tablet, with the appropriate app installed, via a Wi-Fi communication link. The AR2 drone also transmits significant navigation data to the controlling consul during the drone flight. Navigation data is transmitted by the drone every 20ms and includes; t - time of flight, v_x - velocity in the x direction, v_y – velocity in the y direction, and the drone h – height. The velocity values v_x and v_y, are true velocities, calculated from the drone's forward and downward looking cameras; a method attributed to Horn and Shunck – Determining optical flow [21]. The velocity values v_x and v_y are mathematically integrated in the control program enabling a plot of the drone's x-y position of the whole flight to be obtained.

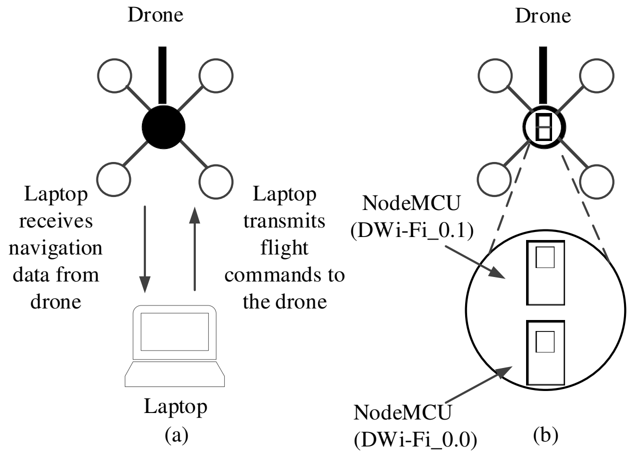


Figure 1 (a) Drone flight controlled via laptop, (b) drone flight controlled by NodeMCU Wi-Fi module

An autonomous drone requires a hardware platform capable of executing a stored program in its memory and the ability to communicate flight commands to the drone via a Wi-Fi communication link (in this case). Two hardware platforms (a) and (b) are illustrated and are depicted in Figure 1.

(a) Control via laptop
(b) Control via NodeMCU Wi-Fi module

Control via laptop (a), requires the installation of the software development kit (SDK) provided by the manufacturer Parrot. The SDK enables user flight control programs to be written in the 'C' programming language and executed, handles drone Wi-Fi connection, enables drone navigation data to be received and transmits flight commands to the drone.

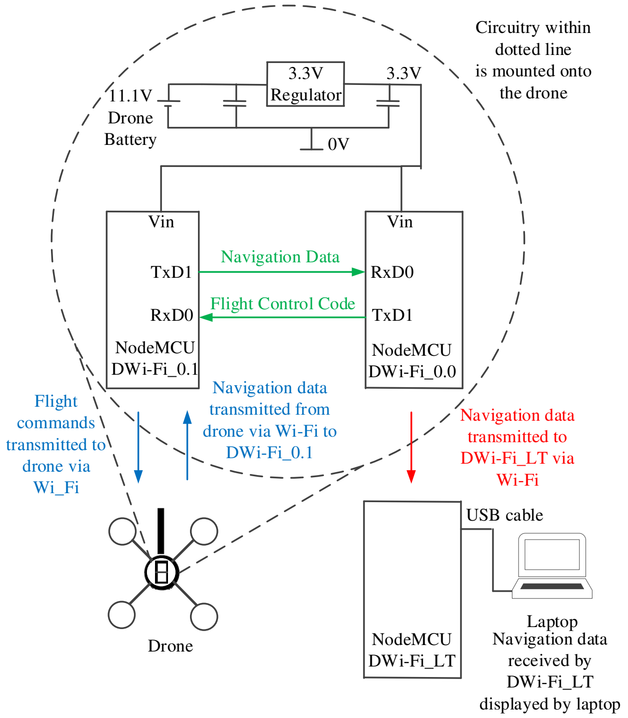


Figure 2 NodeMCU controlled autonomous drone

The NodeMCU Wi-Fi module is an internet of things (IOT) platform incorporating an ESP8266 Wi-Fi module enabling Wi-Fi connectivity, and a microcontroller with 128k of application program memory. The microcontroller has thirty accessible I/O (input/output pins), serial data communications capability, ADC (analogue to digital converter) inputs, and is readily programmed by the Arduino IDE (Integrated Development Environment). The NodeMCU module measures 4.8cm long by 2.5cm wide and weighs 10g. The diagram of Figure 1b depicts two NodeMCU modules labelled DWi_Fi_0.1 and DWi_Fi_0.0. Module DWi_Fi_0.1 connects to the drone Wi-Fi, transmits flight commands to the drone, and reads navigation data transmitted from the drone. The DWi_Fi_0.1 module must be connected to the drone at all times. If the connection is broken the drone is observed to drift uncontrollably. Drone navigation data is required to be transmitted to the laptop for analysis, and the only way this can be achieved without breaking the drone to module Wi-Fi connection, is to include a second NodeMCU module labelled DWi_Fi_0.0. The detail of the hardware circuit is depicted in Figure 2.

The function of the two NodeMCU modules is described below.

DWi-Fi_0.1

(i) connects to the drone Wi-Fi
(ii) communicates flight control commands to the drone
(iii) reads navigation data from the drone
(iv) transmits navigation data via serial port to DWi-Fi_0.0
(v) receives flight control codes from DWi-Fi_0.0 and responds accordingly

DWi-Fi_0.0

(i) enables drone network creation by connecting to other DWi-Fi_x.0 modules of similarly configured drones
(ii) transmits flight control codes across the network
(iii) receives flight control codes transmitted from other drones on the network
(iv) communicates flight control codes to DWi-Fi_0.1 via serial port
(v) receives navigation data from DWi-Fi_0.1
(vi) transmits received navigation data from DWi-Fi_0.1 across the network.

As well as enabling navigation data to be captured and transmitted for analysis, DWi-Fi_0.0 module also enables drone network formation for similarly configured drones. The x in the DWi-Fi_x.0 drone numbering relates to a unique drone number assigned to a drone on the network. Figure 2 also shows a 3.3V voltage regulator connected to the drone battery which is required to supply 3.3V to the two NodeMCU module. An additional NodeMCU module DWi-Fi_LT captures navigation data for analysis.

Table 1 List of flight control codes

Flight code	Flight code function
TO	Take off
FOx	Fly forward (*x* metres)
REx	Fly in reverse (*x* metres)
RLx	Roll to the left (*x* metres)
RRx	Roll to the right (*x* metres)
LA	Land

In the diagram of Figure 2, flight control codes are transmitted from DWi-Fi_0.0 to DWi-Fi_0.1. The flight control code is interpreted by DWi-Fi_0.1 and the corresponding AT flight command transmitted via Wi-Fi to the drone. Upon reception, the drone will execute the command and respond accordingly. Whilst in flight, navigation data is transmitted from the drone to DWi-Fi_0.1 via Wi-Fi, from DWi-Fi_0.1 to DWi-Fi_0.0 via serial port, and finally from DWi-Fi_0.0 to DWi-Fi_LT via Wi-Fi for display and analysis. The available flight codes which can be transmitted by DWi-Fi_0.0 are displayed in Table 1.

B. *Autonomous drone flight control algorithm*

Autonomous drone flight utilising the two NodeMCU modules depicted in Figure 2b is implemented. Flight control is realised by transmitting appropriate AT commands to the drone. The drone AT flight command structure is depicted below.

AT*PCMD_MAG=seq_num,a,b,c,d,e,f,g

Arguments a-g determine the flight mode as depicted in Table 2. The seq_num value is effectively a command counter and, starting from zero, is incremented for every subsequent AT command transmitted. The drone will only execute a command if the seq_num in the current AT command received is greater than the seq_num in the previous AT command executed. A packet of thirty AT commands (for the same original function executed) is transmitted to the drone every 20ms

Table 2 Argument functionality table

a	1	Enables combined yaw mode
a	0	Enables hover mode
b	-1min to +1 max	Roll left/Roll right
c	-1min to +1 max	Forward/Backward
d	-1min to +1 max	Ascend/Descend
e	-1min to +1 max	Anticlockwise/Clockwise
f	0	Calibrate magnetometer
g		Magnetometer accuracy

The AT commands for NodeMCU control are used to construct seven flight control functions as depicted below By combining these functions in the required order any desired flight plan can be realised/

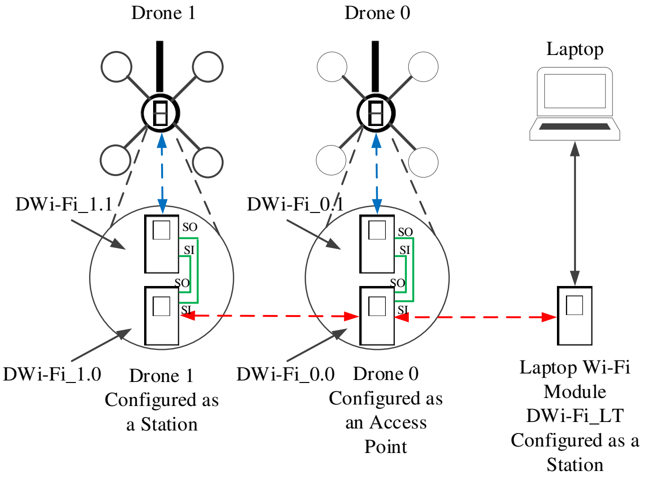
(i) take_off();
(ii) land();
(iii) hover();
(iv) forward_backward(a,b);
(v) roll_left_roll_right(a,b);
(vi) ascend_descend(a,b);
(vii) rotate_clock_anticlock(a,b);

In functions (iv) to (vii) above, the argument ‘a’ determines the distance or number of degrees to be travelled, and argument ‘b’ determines the velocity of travel. The polarity of argument ‘b’ also determines the direction of movement e.g. in the forward_backward function a negative ‘b’ argument will instruct the drone to fly in the forward direction. These functions are located in DWi-Fi_x.1 and are called when this module receives a command code, illustrated in Table 1, from DWi-Fi_x.0.

Within the forward_backward and roll_left_roll_left functions, a distance control algorithm is included to ensure that the drone flies the distance specified by argument ‘a’, and does not overshoot.

C. *Autonomous Dual UAV hardware Configuration*

The diagram of Figure 3 depicting two drones, with the hardware configuration for the NodeMCU controlled autonomous drone described in Figure 2, forms the hardware requirement for the dual autonomous drone network.



Legend

🟥 Wi-Fi communication between DWi-Fi_x.0 modules and DWi-Fi_LT.

🟦 Wi-Fi communications between DWi-Fi_x.1 modules and respective drone.

🟩 Serial communications link between DWi-Fi_x.0 and DWi-Fi_x.1 on the same drone.

Figure 3 Dual drone network hardware configuration

The diagram of Figure 3 illustrates the two NodeMCU modules DWi-Fi_x.0 providing network capability (red communication link), enabling flight command codes to be transmitted between the drones and also enabling drone navigation data to be transmitted to DWi-Fi_LT for analysis. The DWi-Fi_x.1 modules enable flight commands to be transmitted to the respective drone and receive navigation data from the connected drone (blue communication link). Both NodeMCU modules on each drone communicate with each other via the serial port communication link (green communication link). Command codes can be transmitted from DWi-Fi_x.0 to DWi-Fi_x.1, and navigation data received by DWi-Fi_x.1 from the drone transmitted to DWi-Fi_x.0. Navigation data received by DWi-Fi_x.0 can then be transmitted over the network and received by DWi-Fi_LT.

Within the network described in Figure 3, drone 0 (DWi-Fi_0.0) is configured as an access point, drone 1 ((DWi-Fi_1.0) is configured as a station, and the laptop module DWi-Fi_LT is configured as a station.

III. RESULTS AND ANALYSIS

A. *Single autonomous drone flight test*

The flight plan of Figure 4 is implemented to examine the performance of the single autonomous flying drone. The drone is instructed to take-off, hover for 9s, climb to 1.5m, fly forward for 14m, hover for 3s and finally land. The program required to achieve this flight plan is shown below.

```
(i)        take_off();
(ii)       hover(9);
(iii)      ascend_descend(1500,0.1);
(iv)       forward_backward(14000,-0.1);
(v)        hover(3);
(vi)       land();
```

In (i) the drone is instructed to take off. In (ii) the drone is instructed to hover. The argument indicates the hover time which in this case is nine seconds. In (iii) the drone is instructed to ascend. The first argument is the height to which the drone should ascend. The second argument, being positive, means the drone should ascend. A negative value would inform the drone to descend. The actual value determines the velocity of ascent where a value of 1.0 is the maximum. In (iv) the drone is instructed to fly a distance of 14000mm (specified in the first argument). The second argument being negative instructs the drone to fly in the forward direction. A negative value would inform the drone to fly in the reverse direction. The numerical value determines the velocity of flight. A value of -0.1 corresponds to an actual velocity of 1.5m/s. In (v) the drone is instructed to hover for three seconds and finally in (vi) the drone is instructed to land. The diagrams of Figures 5 and Figure 6 illustrate the performance of drone whilst executing the flight plan program.

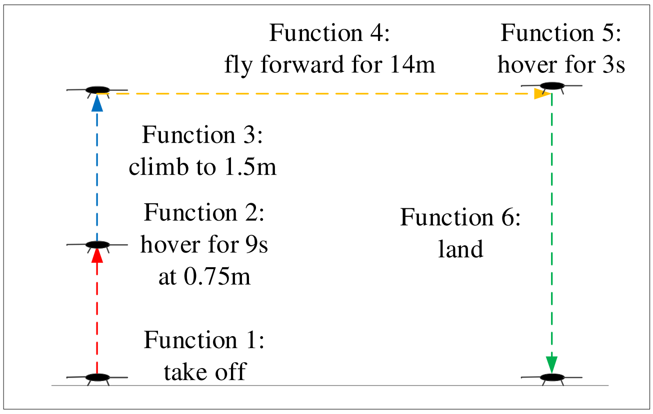


Figure 4 Flight plan to examine the performance of the single autonomous flying drone

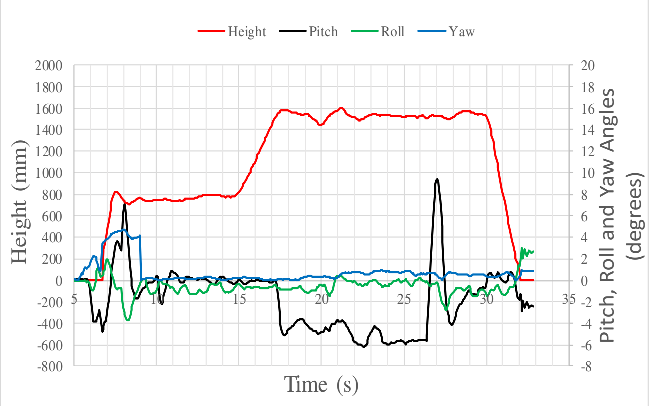


Figure 5 Graph of Pitch, Roll and Yaw, and Height plotted against time for the flight plan of Figure 4

At time 5.6s in Figure 5 the take-off function has been executed, movement is observed in the pitch, roll and yaw angles, and the drone lifts of the ground. The hover function begins execution at 5.6s and continues execution for 9s as requested in the program until completion at 14.6s. Once stabilised, the drone is observed to hover at a height between 740cm and 800cm. At 14.6cm, the drone is observed to climb to 1600mm before finally settling at 1520cm. At 17.2s, the drone has completed its ascent and begins execution of the fly forward phase of the program. The drone is observed to pitch forward 5 degrees indicating that the drone is about to move in the forward direction.

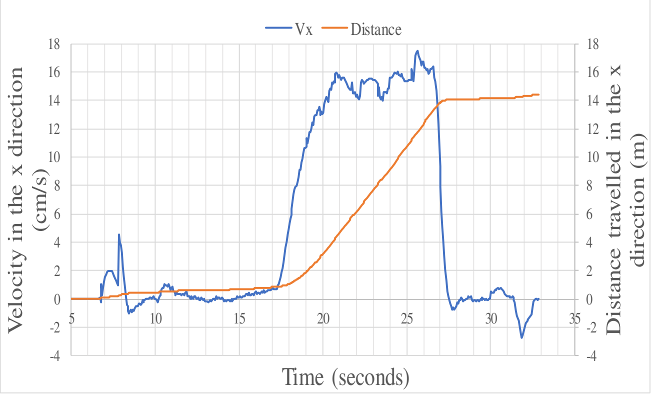


Figure 6 Graph of velocity in the x direction and distance plotted against time for the flight plan of Figure 5

In the graph of Figure 6 the velocity in the x direction is observed to begin to increase at 17.2s and the drone moves in the forward x direction. At 26.4s the 3s hover is executed. In Figure 5, the pitch angle is observed to pitch backwards acting as a brake. The velocity in the x direction in Figure 6 falls to zero and the drone is observed to stop its forward motion after completing 14m. The drone is observed to hover for a further 3s in the graph of Figure 6 before landing. The drone thus completes the required flight plan of Figure 4 as expected and is therefore able to complete any desired flight plan as instructed by the controlling program.

B. *Dual drone flight test*

The algorithm, instructing network formation, informing both drones to take off, hover for five seconds, and then land is described in the flowchart of Figure 7.

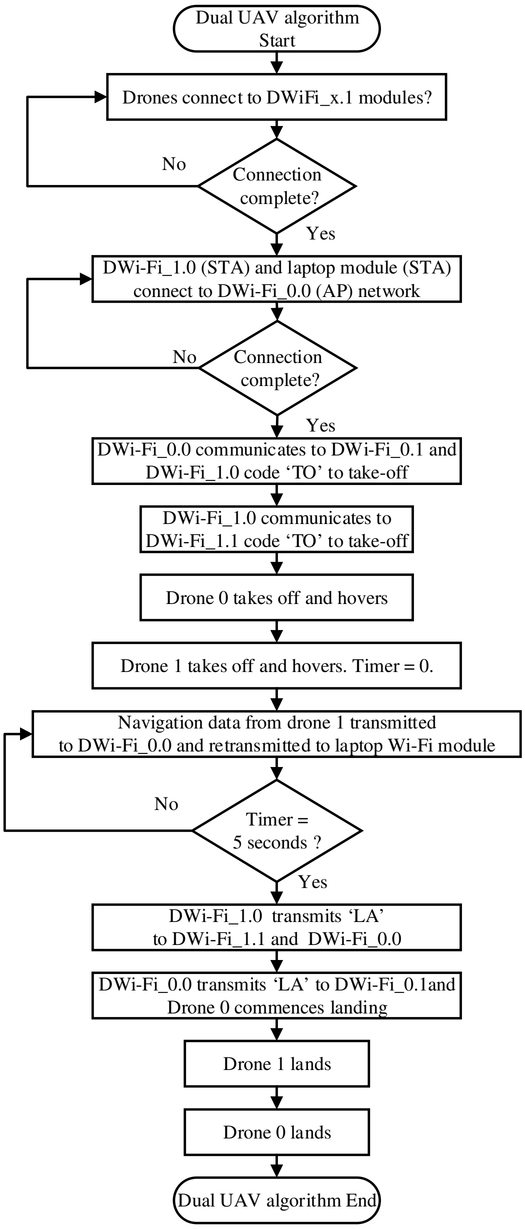


Figure 7 Flowchart describing the two drone flight algorithm

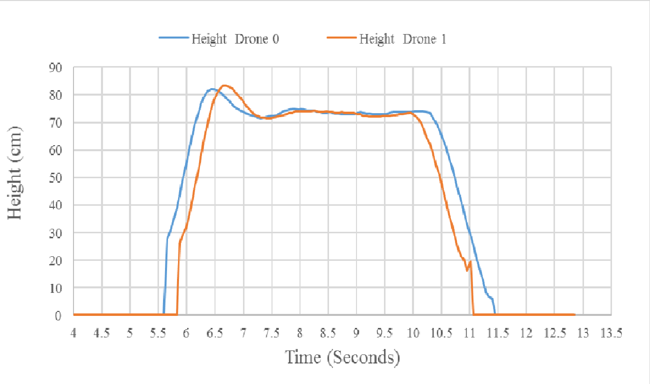


Figure 8 Graph showing take off, height, and landing of two networked drones

The programs described in the flowchart of Figure 7 are uploaded to the respective Wi-Fi modules. Power is applied, and after a few seconds, while the Wi-Fi network is established, both drones' rotors begin to rotate and the drones leave the ground. Both drones hover at a height of 73cm for approximately five seconds before landing. The graph of Figure 8 shows both drones completing the desired flight plan. What is also clear from Figure 8 is the delay between drone 1 and drone 0 taking off and landing where a 0.2 second delay is observed between drone 0 and drone 1 taking off. A similar delay is observed when the drones land where drone 1 lands 0.2 seconds before drone 0. The delays between take-off and landing are also confirmed by visual inspection whilst observing the drones' flight. The order of take-off of the two drones might be expected by a consideration of the flowchart of Figure 7 where the take-off command code 'TO' is clearly executed by drone 0 before drone 1 ensuring drone 0 takes off first. Similarly when the hover duration is complete, drone 1 executes the land command code 'LA' before drone 0 ensuring that drone 1 lands before drone 0. The approximate 0.2 second delay incurred between take-off and landing is attributed to the delay of the command code being transmitted across the network.

IV. CONCLUSION

Results from the single autonomous drone test flight show that two NodeMCU Wi-Fi modules strapped to the drone provide a hardware platform required for autonomous drone flight control. The programs required to control aspects of drone flight, such as fly forward or backward, are written as functions with two arguments to enable the user to input the distance the drone should travel, and the velocity of travel. Combining the flight control functions enable any desired drone flight path to be realised.

The distance travelled by the drone in both the x and the y directions are calculated during the flight by effective integration of the available velocities in the x and y direction v_x and v_y with respect to the flight time t. The resulting incremental distance values in the x and y direction enables the drone flight to be drawn as an x, y plot. The accuracy of the distance travelled is absolutely dependent upon the accuracy of the velocity data transmitted by the drone. The manufacturers Parrot state that the accuracy of this data is dependent upon the terrain over which the drone flies where a regular pattern such as square tiles will provide the most accurate data. When measured, the accuracy of the calculated distance flown by the drone is found to be variable with distance accuracy values of 90% to 99% obtained.

The hardware of the single autonomous drone provides the platform for a dual drone system. Two drones employing the same hardware enables the formation of a two drone network. Two or three character command codes communicated over the network control the flight plan of the two drones. Transmitting combinations of the available flight command codes across the network enables any flight plan to be realised.

Further work will involve the expansion of the drone network. This will be realised by the development of a discovery algorithm to enable all station drones within the range of the access point drone to join the network.

Currently there is no provision for the drones to determine their relative positions and flying more complex flight plans has the potential to incur flight collision. Further work will investigate methods to establish drone position. A possible non-intrusive method, not requiring additional hardware would be to consider the received signal strength of the Wi-Fi signal between access point and station drones.

REFERENCES

[1] (June 2013) The Teal Group Corporation: Teal Group Predicts Worldwide UAV Market Will Total $89 Billion in Its 2013 UAV Market Profile and Forecast. [Online]. Available: https://www.tealgroup.com/index.php/pages/press-releases/40-teal-group-predicts-worldwide-uav-market-will-total-89-billion-in-its-2013-uav-market-profile-and-forecast

[2] (2016) Goldman Sachs: Drones: Reporting for Work. [Online]. Available: https://www.goldmansachs.com/insights/technology-driving-innovation/drones/

[3] Parrot. [Online]. Available: https://www.parrot.com/uk/drones/parrot-ardrone-20-elite-edition

[4] DJI Forum: RC vs WiFi. [Online]. Available: https://forum.dji.com/thread-124974-1-1.html

[5] 3DR. [Online]. Available: https://3dr.com/

[6] M. Sheehan. (2019) Top 100 drone companies to follow in 2019. [Online]. Available: https://mydroneauthotity.com

[7] (2018) US Department of Transport: FAA Drone Registration Tops one million. [Online]. Available: https://www.transportation.gov/briefing-room/faa-drone-registry-tops-one-million

[8] D. Ayemba. (2018) Utilising drone technology in construction. [Online]. Available: https://constructionreviewonline.com/2018/03/drones-in-construction/

[9] G. Ding, Q. Wu, L. Zhang, Y. Lin, T. A. Tsiftsis, and Y. Yao, "An Amateur Drone Surveillance System Based on the Cognitive Internet of Things," *IEEE Communications Magazine,* vol. 56, no. 1, pp. 29-35, 2018, doi: 10.1109/MCOM.2017.1700452.

[10] J. Ye, H. Chen, and W. Tsai, "Panorama Generation Based on Aerial Images," in *2018 IEEE International Conference on Multimedia & Expo Workshops (ICMEW)*, 23-27 July 2018 2018, pp. 1-6, doi: 10.1109/ICMEW.2018.8551548.

[11] D. Yavuz, H. Akbıyık, and E. Bostancı, "Intelligent drone navigation for search and rescue operations," in *2016 24th Signal Processing and Communication Application Conference (SIU)*, 16-19 May 2016 2016, pp. 565-568, doi: 10.1109/SIU.2016.7495803.

[12] S. Bernardini, M. Fox, and D. Long, "Planning the behaviour of low-cost quadcopters for surveillance missions," in *Twenty-Fourth International Conference on Automated Planning and Scheduling*, 2014.

[13] D. Lee, J. Zhou, and W. T. Lin, "Autonomous battery swapping system for quadcopter," in *2015 International Conference on Unmanned Aircraft Systems (ICUAS)*, 9-12 June 2015 2015, pp. 118-124, doi: 10.1109/ICUAS.2015.7152282.

[14] P. Cohn, A. Green, M. Langstaff, and M. Roller, "Commercial drones are here: The future of unmanned aerial systems," *McKinsey & Company,* 2017.

[15] (2019) Dronethusiast: Best Drones with Longest Flight Times. [Online]. Available: https://www.dronethusiast.com/best-drones-with-longest-flight-times/

[16] E. Yanmaz, S. Yahyanejad, B. Rinner, H. Hellwagner, and C. Bettstetter, "Drone networks: Communications, coordination, and sensing," *Ad Hoc Networks,* vol. 68, pp. 1-15, 2018/01/01/ 2018, doi: https://doi.org/10.1016/j.adhoc.2017.09.001.

[17] L. Gupta, R. Jain, and G. Vaszkun, "Survey of Important Issues in UAV Communication Networks," *IEEE Communications Surveys & Tutorials,* vol. 18, no. 2, pp. 1123-1152, 2016, doi: 10.1109/COMST.2015.2495297.

[18] E. Darack. (2017) A Brief History of Quadrotors. *Air and Space/Smithsonian Magazine* [Online]. Available: www.airspacemag.com

[19] Z. Tianqu and J. Hong, "Landing system for AR.Drone 2.0 using onboard camera and ROS," in *2016 IEEE Chinese Guidance, Navigation and Control Conference (CGNCC)*, 12-14 Aug. 2016 2016, pp. 1098-1102, doi: 10.1109/CGNCC.2016.7828941.

[20] R. Schurig, T. Désesquelles, A. Dumont, E. Lefranc, and A. Lux, "3D stereoscopic measurements from AR Drone Squadron," in *2014 IEEE International Conference on Control Science and Systems Engineering*, 29-30 Dec. 2014 2014, pp. 23-26, doi: 10.1109/CCSSE.2014.7224501.

[21] B. K. Horn and B. G. Schunck, "" Determining optical flow": A retrospective," 1993.