Implementation of Matrix Drone Show Using Automatic Path Generator with DJI Tello Drones

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***Abstract*— In this paper described the process of designing and applying 100 DJI Tello EDU drones to display various characters following from A to Z and 0 to 9 as letters and words. The drones are divided into four groups, each of 25 drones. Each drone is connected to a wireless access point where the mission control center operates the command to each drone individually in parallel to display the expected letter or words. Python is the programming language used for commanding and controlling the operation. The communication between drones and the mission control computer is done wirelessly with Wi-Fi 802.11N technology running at a 2.4GHz frequency. Each drone is assigned to a specific IP address as an ID based on the unique Media Access Control (MAC) address. To communicate with the drones, the User Diagram Protocol (UDP) protocol is used for the communication. As a result, the matrix drone can perform different flights showing different characters and words including various custom 3D shapes.**

Keywords*— Automatic Drone Path Generator, DJI Tello EDU, Matrix Drone, Python, Swarm Drone, Wi-Fi 802.11N

I. Introduction

The drone is fast-growing research in both control engineering and design, nowadays mini drone is a small and compact drone that could run on a low-capacity battery that could fly from 10 to15min. Due to the small size and a reasonable flight time, these drones could be programmed to perform matrix-like flight paths for indoor applications [1]. Small-size mini drones are not equipped with GPS receivers for self-positioning. These lead to the requirement and rely on an on-board inertial measurement unit (IMU) and on-board camera for vision positioning and let the drone fly without the GPS, the downside of this kind of drone is unstable of holding position due to strong wind, low light and cannot fly in complete darkness [2]. In this paper, Fig. 1. the DJI Tello EDU drone is used for this application. These mini-drones use onboard IMU and camera for measuring self-movement and positioning, the drone can accept commands wirelessly using an open-source platform that could program using Swift, Scratch, and Python. For the drone's specification, the drone can fly with a range of 100m and a maximum height of 30m. The drone weighs 87g with a 4.18Wh battery capacity, which can fly approximately 13min [3]. In this drone implementation, the drone was not controlled remotely using a remote control, but rather control via programming. Python is the main language used for commanding and controlling drones.

Fig. 1. DJI Tello EDU

II. Design of Matrix Drone System

This section describes the process of designing the flight path concept and simulation including the design of the module for the drone's attachment. The section is divided into five parts as follows.

A. Drone's Communication Diagram

Fig. 2 shows the block diagram of a single drone configuration. For factory default, the drone is enabled as a wireless access point for a smartphone or computer to connect to, henceforth the drone needs to be set to operate as a client mode that connects to a wireless access point instead, following the SDK manual provided by RYZE Tech [4].

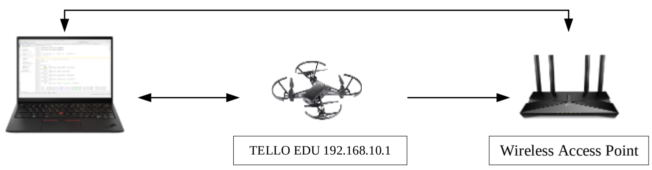


Fig. 2. Single Drone Configuration

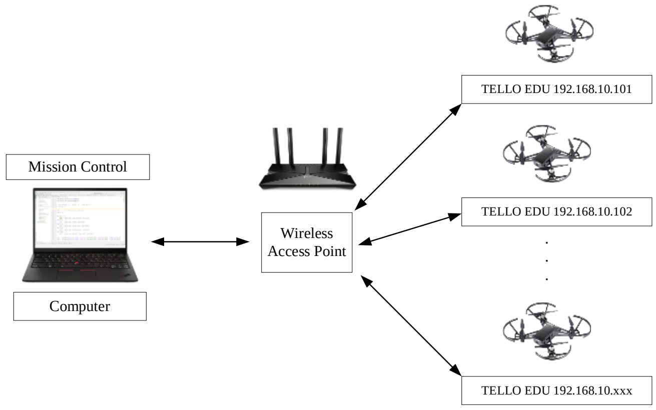


Fig. 3. Multi Drone System Configuration

To control the multi drones, the Mission Control Computer (MCC) is connected to the same network as the drones shown in Fig. 3. The MCC sends commands to the drones via UDP protocol [5] – [6].

B. *Drone Grouping Diagram*

The 100 drones are separated into four groups, each group containing 25 drones unit. Each drone has its unique IP address, to simplify the IP address in each group. The IP address range is divided into 25 IP lists per group as shown in Table. I.

TABLE I. DRONE'S IP TABLE

Drone's Group	Drone's IP Range
Group 1	192.168.10.101 – 192.168.10.125
Group 2	192.168.10.126 – 192.168.10.150
Group 3	192.168.10.151 – 192.168.10.175
Group 4	192.168.10.176 – 192.168.10.200

Fig. 4. is the top view of the drone grid. Each group is a 5x5 matrix. The gap between each drone is 50cm, including 70cm spacing between each group. For testing purposes, the drone is divided into five steps of flight height. The height limited in this testing is 5m, due to the takeoff height of the drone being 80cm. The maximum height set for flight is 500cm shown in Fig. 5.

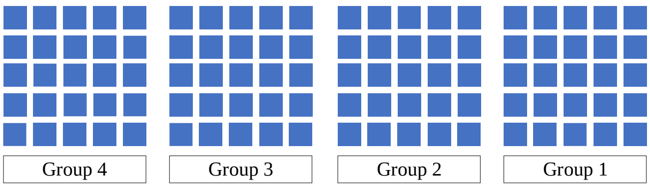


Fig. 4. Drone's Group Diagram

Fig. 5 shows the drone's flight at each height grid. The height gap between each drone is 90cm. Since the drones are flying close to each other, to minimize the drone turbulence during the hovering, the drone is arranged in a tilting position. This helps reduce drone instability during hovering and prolongs the drone flight time rather than reducing the battery while trying to maintain stability during turbulence.

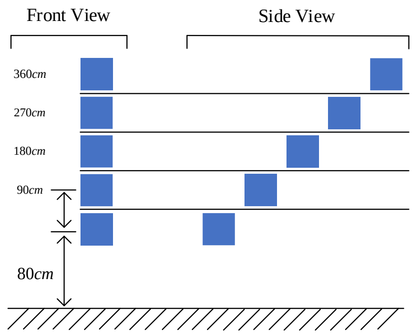


Fig. 5. Drone's Flight Height

C. *Character Design for Matrix Drone*

As mentioned in Fig. 4 the drones are prepared as matrices configuration. Hence the character design is based on a 5x5 character. Fig. 6. is an example of the drone configuration as NPIC text. The grayed-out tile is the drone commanded as not flying, the blued color tile is presented as the flying drones. The available character and letter include the A-Z and 0-9 characters.

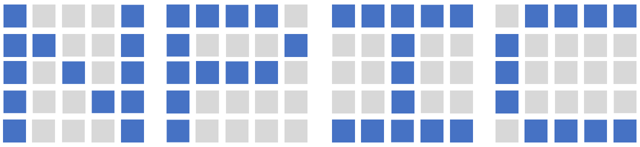


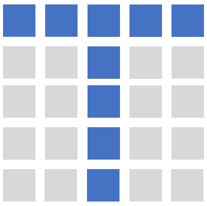
Fig. 6. Matrix Drone Character for NPIC

D. *Automatic Path Generator Design*

The following pseudocode described the automatic path generator for any characters. To generate a flight path, a file of the "CharacterMap" is required, this file contains the pixel of the character as binary as shown in Fig. 7 (a). The pixel of the character is referenced to the character of visual drone flight in Fig. 7 (b).

```
'T': [
    '1', '1', '1', '1', '1',
    '0', '0', '1', '0', '0',
    '0', '0', '1', '0', '0',
    '0', '0', '1', '0', '0',
    '0', '0', '1', '0', '0'
],
```

(a)



(b)

Fig. 7. Pixel Map for 'T' Character

Automatic Path Generator

BEGIN

DATA: Read Character's Map
INPUT: Input Flight Height and, Input Character

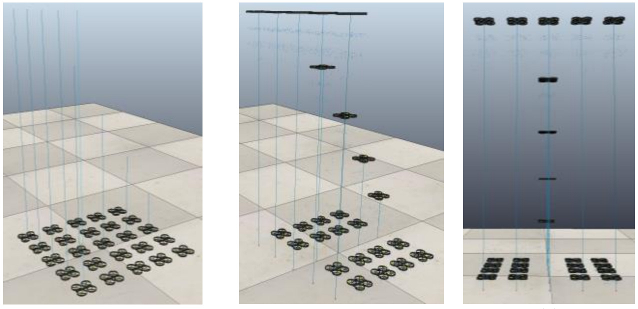
PROCEDURE:
Create Flight Path File for Character
Read Pixel Point of Character's Map

FOR Pixels in Character ***DO***
Select Height for Each Pixel
Write Pixel Path to File
END FOR

OUTPUT: Save Generated Path File
END

E. Drone Simulation in CoppeliaSim Software

To clarify the design, the simulation was conducted on CoppeliaSim simulation software. Fig. 7 (a) is the drone preparation for group 1 drone, the blue lines are the flight path for each drone in the group. Notably, the flight path is programmed to automatically generate the selected character. Fig. 7 (b) and (c) are the steady-state of the drone for a complete flight of the 'T' character.



(a) (b) (c)

Fig. 8. Simulation of Matrix Character for Letter 'T'

The drones stay on the ground and represent the rest state of the drones in the group. These drones only activate flight mode only when the drone is required for the character in each flight.

F. LED Module for The Drones

To make the drone more visible during flight, the LED module attachment was designed to attach directly on top of the drone. In Fig. 8 (a) the LED holder was 3D printed using ABS material. The complete module contains the holder, LED, MCU, and battery. The complete setup is shown in Fig. 8 (b).

(a) (b)

Fig. 9. 3D Printed LED Module

To reduce the payload from the drone, the module is designed with very lightweight components possible. The CR2032 battery is chosen due to its lightweight and higher voltage rating than Alkaline batteries. By adding these batteries in series, it could provide enough voltage and current to operate the MCU and LEDs.

(a) (b) (c)

Fig. 10. LED Module's Components

III. Experimental and Implementation

To ensure a safe drone flight implementation, flight experiments were conducted. The "Test Flight Preparation" and "The Flight for Single Character" was set up to test both networking and drone flight test.

A. Test Flight Preparation

In-flight preparation diagram shown in Fig. 10, there is one computer required for running the overall operation. The MCC commands the drones and organizes the flight path for each drone's flight to form specific characters or words. The networking part contains a network switch and two wireless routers. The purpose of using two wireless routers gives a better performance both in low latency and stability over a single wireless router. Each wireless router has two groups, "MC_NET_1" and "MC_NET_2" which contain 50 drones and is divided into two groups of 25 drones in a total of four drone groups. Using the network switch, allow us to join the two wireless router into a single network making the communication more standardized for the drones and MCC in operation. Moreover, separating the router into two different wireless networks allows us an easier way to control the drone in case of a network error situation. This allows us to put the connected drones into emergency mode and started lading after receiving the command. Without receiving the command for 15s the drone will enter the self-auto landing mode [7].

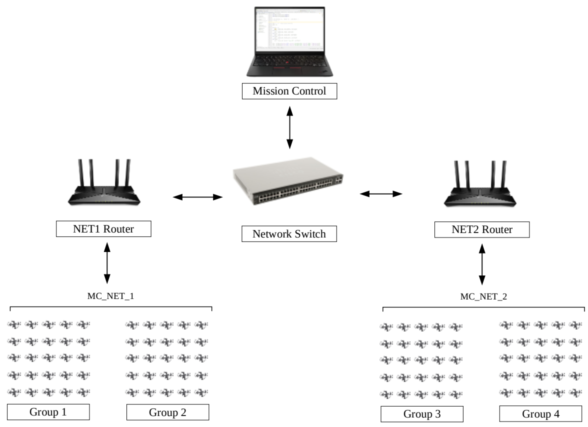
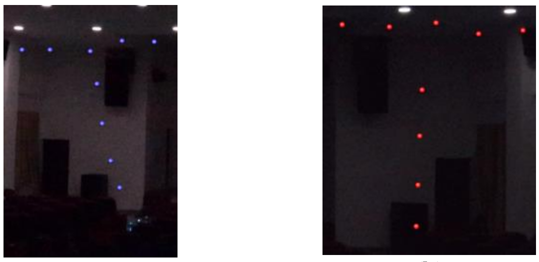


Fig. 11. Complete System Preparation Diagram

B. Test Flight for Single Character

To ensure safety before the full 100 drone flight, the experimental flight for a single character in a total of 25 drones was conducted. In this experiment, all the network devices are enabled but the drones are only turned ON in Group 1. The flight commands were sent to the groups for testing [8] – [9].



(a) (b)

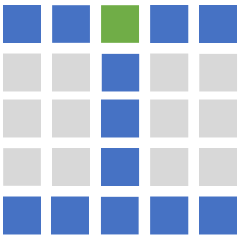
Fig. 12. Flight Test for Single Character 'T'

As shown in Fig. 12, the drones can fly as expected from the mission control command. The flight was conducted twice for showing the letter 'T' in Fig. 12 (a) and (b). For each flight, the drones must hover for a specific period to make the character readable.

C. *Drone's Flight Procedure*

Each character flight must maintain 1min and 30sec combined with hovering, takeoff, and landing of total flight time. Notably, the drone follows the instructions for each flight provided by the mission control computer. In Table. II, the highlighted green block is the example drone for the flight. The left side of the table contains the eight steps of a complete flight for the highlighted. The "command" instruction enables the drone to accept the SDK instruction sent from the mission control computer. Before the flight, the "takeoff" instruction let the drone take off and hover in the air. The "go 0 0 360 100" commands the drone to fly to the coordinate of (x=0, y=0, z=100) with a speed of 100m/s. The "hover 50" commands the drone to stay in the air for 50 seconds, "land" command tells the drone to land on the launch pad. In the final "battery?" command, check the drone's battery after the flight.

TABLE II. FLIGHT INSTRUCTION FOR SINGLE DRONE

Instructions	Highlighted Drone for Flight
1. command 2. takeoff 3. go 0 0 360 100 4. hover 50 5. go 0 0 -360 100 6. hover 10 7. land 8. battery?	

During the flight, the data obtained from the drone shows a significant difference. Each instruction sent to the drone cannot be sent simultaneously but rather to wait until the drone responds with "OK" before the next command can be received and can execute. In actual flight, the "OK" response from the drone can be received only when the drone executes the command successfully with stability. Table III shows the execution duration of each instruction for the drone flight time mentioned in Table II. Notably, the execution duration may vary due to the effect of the environment such as big wind or low light conditions [10] – [19].

TABLE III. DRONE'S INSTRUCTION EXECUTION TIME

Instruction	Execute Duration
command	<1ms
takeoff	6s 63ms
go 0 0 360 100	3s 47ms
hover 50	50s
go 0 0 -360 100	5s 5ms
hover 10	10s
land	3s 15s
battery?	<1ms

To prevent the drone from crashing during takeoff and landing, the mission pad for DJI Tello EDU is used. The mission pad has a unique number ranging from 1 to 8, the drone uses the number and various symbols on the pad to localize after takeoff and position before landing.

Fig. 13. Drone with Mission Pad

D. *Matrix Drone Flight Result*

Fig.14 shows the matrix drone preparation with different LED colors for each group. The following Fig. 15 shows the custom shape of the top of Angkor Wat, in Fig. 16 shows the flight of the "NPIC" text. Fig. 17 shows the drone's flight as the "2022" number.

Fig. 14. Drone Grid Preparation

Fig. 15. Flight Shape As The Top of Angkor Wat

Fig. 16. Flight Text as "NPIC"

Fig. 17. Flight Number as "2022"

IV. Conclusion

Following the experiment result, the matrix drone could perform the flight with commanded words, letters, and custom symbols. Due to the various wireless interference from surroundings, the drone faced the issue of network interruptions. The commonly used 2.4GHz Wi-Fi channel can overlap the same Wi-Fi channel used by the drone network. The interference randomly makes the connection between the drones and the router unstable, high latency, and delays data transferring. The drone is highly suggested for flight in an area with low wind speed due to stability concerns. While running the image processing of mission pad detection could lead to drone overheating issues in less ventilated areas, making the drone manually land and shut down. To further reduce the networking interference, the 900MHz wireless module is suggested due to the long-range capability and low usage in an urban area.

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