Brain-Computer Interface for Quadcopter Morphology Manipulation

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***Abstract*—Quadcopters have been around for a long time and have recently been entering various fields with varied applications, from recreational flying to experimental urban taxis. Technological improvements have made it possible for quadcopters to adapt to their deployed environments by folding and changing shape mid-flight. This paper presents a notable insight into how to morph the shape of a quadcopter using mental commands from a brain-computer interface headset. The comparisons made in this paper range from the morphing quadcopter design specifications to the reduction in user response time by using mental commands versus a physical switch.**

Keywords—drone, morphology, BCI, quadcopter, Pixhawk, Emotiv

I. Introduction

Quadcopters have many advantages, reducing human risk to perform various laborious tasks such as surveying large areas [1] or improving agriculture [2]. Moreover, the current market price is more affordable than before, making quadcopters suitable for modification and academic research.

Much research on quadcopters/drones has been done to improve their performance [3-5] and features like image processing techniques [6] and heavy payload application [7]. A morphing drone [8-10] can help users since it can allow medium to large drones to squeeze through narrow apertures and obstacles and then change the morphology (shape) back to the normal flight morphology, which provides efficient flight time and maneuverability.

The traditional method to control a drone is using a wireless RC transmitter, and later came the method of establishing a Wi-Fi or Bluetooth computer connection. However, this paper demonstrates an additional method for users to interact with quadcopters without moving any part of the body. Brain-Computer Interface (BCI) systems can translate user's intentions and generate control signals which computer or external machine can understand, by analyzing the neurophysiological signals [11]. In general, a brain-computer interface (BCI) is communication between brain signals and an external, digital device like a computer. A non-invasive BCI device will capture electroencephalography with electrodes placed on the user's scalp and then decode the signals into human-readable data such as cognitive states (moods), mental commands, or even facial expressions. These strategies have the drawback of not reflecting the natural way of planning a movement. To achieve an ecological and intuitive control, the movements decoded by the BCI need to be closely related to the user's intention [12].

This study focuses on controlling the morphology (shape) of quadcopters by using a non-invasive BCI headset to send mental commands to the onboard microcontroller of the quadcopter. It starts by constructing a morphing drone utilizing a mechanism to contract the propellors of the quadcopter inward (e.g., using servo motors or elastic bands). The next step is to train the specific user to fly the morphing quadcopter by using their brain signals to change the quadcopter's morphology when needed.

II. Morphing Quadcopter

A. Design of Mechanic System

The drone frame is created by 3-D printing to provide rapid prototyping, consistency, and simplicity for modification. The structure consists of four parts: the top framework, bottom framework, four arms, and four arm supporters. All the pieces are printed with 75% infilled to provide the strength for enduring torque from the brushless motors and lightweight to give the quadcopter optimal flight time.

B. Design of Electronic System

The quadcopter is built around the size of racing drones (250-300 mm) after considering prices and availability. The first component is a Pixhawk4 flight controller because of its high reliability and open-source software. The Pixhawk4 transmits signals to the 33A 2~5S electronic speed controllers (ESCs). The EMAX 2306-2400kv brushless motors are used for this design due to their compatibility because the quadcopter's size requires high Kv motors to operate. Users can manually change the morphology of the quadcopter by toggling a switch from an RC transmitter. The signal from the RC transmitter is received by the ESP32 microcontroller, which is in charge of sending signals to the servo motors to change morphology.

C. Powering the System

A 12v 2200 mAh 3-cell Lipo battery will supply the power management board, and the board will power the four ESCs to regulate voltage for the four brushless motors. The power management board also has two regulators that convert 12v into 5v for supplying the Pixhawk4 flight controller and a backup system. The other 5v regulator is dedicated to the ESP32 and four servo motors.

D. Software

ArduPilot Mission Planner is open-source software that allows us to modify all the Pixhawk firmware configurations needed to fly the quadcopter.

E. Morphing System and Performance

The servo-based morphing quadcopter can morph into three morphologies (shapes): the default X, the H, and the O profiles. Each profile has different characteristics in its size and flight time. As shown in Table I, the X profile is the most user-friendly and has the best flight time since the four motor positions are evenly distanced. The H profile has a shrunken x-axis propeller width and, therefore, an extended y-axis length (like the letter "H"). The four motors are not evenly distanced; thus, the flight time of this shape was found to decrease by 40%. Lastly, the O profile is the smallest form that the quadcopter can take on and has the best flight time performance since motors are well distanced. The only drawback is that the quadcopter trends to drift sideways while it is hoovering because the motors are off-balanced, which can be improved by tuning the PID in the Pixhawk controller.

TABLE I. COMPARING SIZE AND FLIGHT TIMES OF MORPHOLOGIES

Shape	X	H	O
Size (x,y) (cm)	36, 36	29, 45	33, 33
Size by ratio	1,1	0.81, 1.25	0.91, 0.91
Flight time (s)	350	209	340
Flight time by ratio	1	0.6	0.97

Fig. 1. Servo-based morphing quadcopter & the X, H, and O morphologies.

III. BRAIN-COMPUTER INTERFACE

A. Hardware

Fig. 2. Emotiv EPOX X BCI Headset

The Emotiv EPOX X BCI headset (shown in Fig. 2) is used for detecting the brain signals of the user in the form of mental commands. It has 14 channels for each electrode and a sampling rate of 256 samples per second (SPS) with a 2048 Hz internal frequency. The headset supports resolutions from 0.1275uV up to 0.51uV.

B. Software

The Emotiv BCI-OSC application is software that manages the user's mental commands between devices and allows users to train their own profile. The software will stream mental commands from the Emotiv BCI headset to a local host computer (using a local Wi-Fi network) and lastly to the ESP32 Devkit software. The ESP32 is the microcontroller of choice because it has a built-in Wi-Fi chipset that can receive the BCI-OSC commands to eventually change the servo motor angles. A fail-safe switch is also implemented, preventing undesired mental commands when they appear.

IV. INTEGRATION

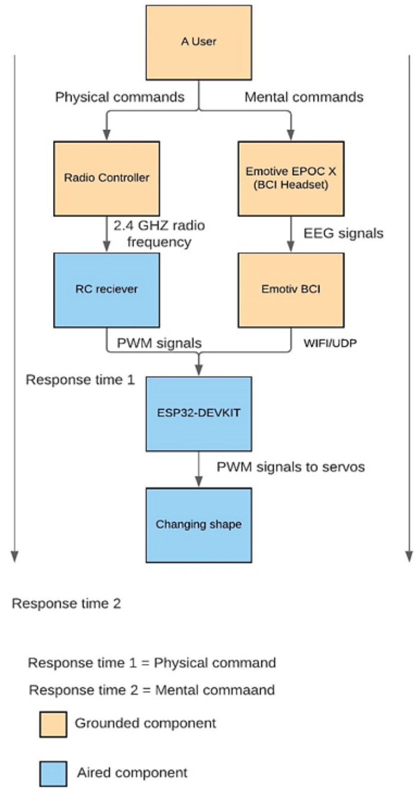

Fig. 3. Physical and Mental Command Flowchart

Fig. 3 and Fig. 4 lay out the directions of signals between components located near the user or on the quadcopter. The user will wear the Emotiv BCI headset, which is connected to a nearby computer via Bluetooth connection. Mental commands will be streamed from the headset to the computer with the Emotiv BCI-OSC software to the ESP32 onboard the quadcopter. On the other hand, the user will use the handheld controller (RC transmitter) to transmit movement telemetry data to the Pixhawk flight controller onboard the quadcopter (first being received by the RC receiver). The ESP32 and the Pixhawk will act independently, sending PWM signals to the servo motors and ESCs, respectively. As previously mentioned, both the microcontrollers are powered by the Lipo battery after going through two regulators and the power management board.

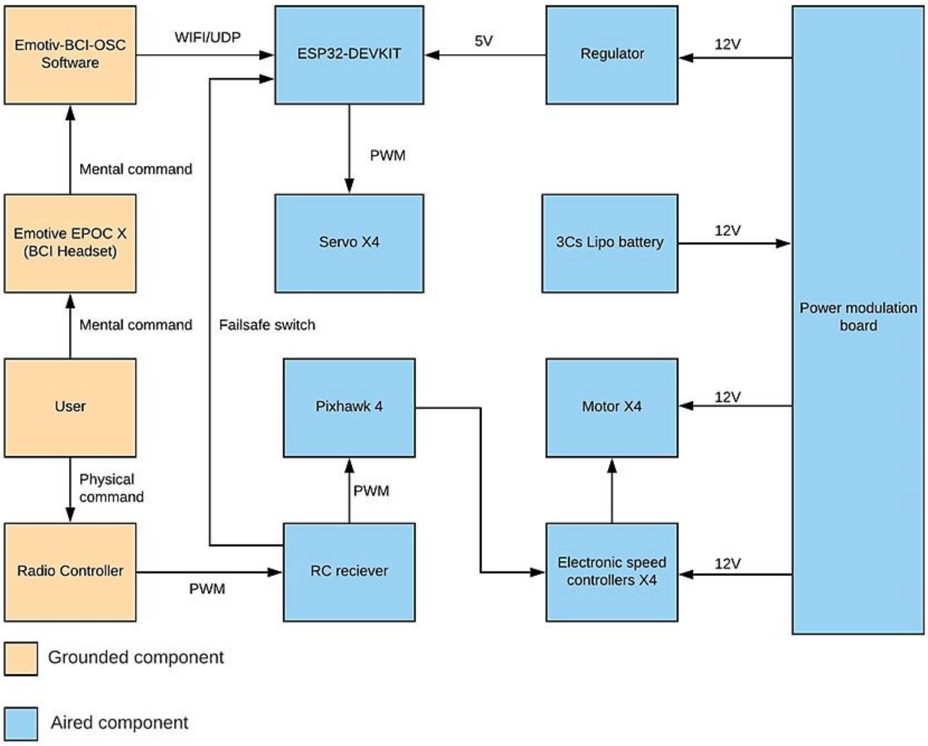

Fig. 4. Power distribution diagram for the morphing quadcopter.

V. Methodology

A. Training

The subject is asked to wear the Emotiv headset and train three mentals command. The commands are neutral, push, and pull. The training process starts with letting the subject practice with neutral until the subject is comfortable with the state of neutrality, which takes approximately 20-30 training sessions. Then the push and pull mental commands are trained using the same technique as mentioned for the neutral command.

B. Data Processing

The mental commands that are streamed from BCI-OSC have values between 0 to 1 depending on the state of mind of the subject at the particular time. The ESP32 will act as a filter to decide if the mental command is intentional or an unintentional signal spike from the user. The filter profile of the ESP32 will need to eventually adjust according to the user since each person has different brain activities, even for the same task.

C. Experimental

After the subject familiarizes themselves with those mental commands, they will be asked to use the same procedure to change the shape of the drone instead (without flying the drone to be sure that the subject is in control of those commands). At this point, the filter on ESP32 helps the subject's commands to work more precisely. The subject will fly the quadcopter (with the mental command function turned off) and use the switch on the RC transmitter to change the shape of the quadcopter to let them observe each quadcopter morphology. Lastly, the mental command function is turned on, and the subject can fly the quadcopter and freely morph it with the user's mind.

VI. Comparison

A. Methodology

Three subjects were asked to participate in the mental command training by first staring at a blank screen for a few random seconds, between 0 to 5 seconds. The screen showed a red circle in the middle after the wait. In the first attempt, the subjects needed to switch a button that changed the quadcopter's shape on the same RC transmitter that was used for flying. For the second attempt, the subjects used the same software, but instead, the subject wore the Emotiv BCI headset and used mental commands instead of the RC transmitter. The time between the red circle appearing until the feedbacks were received from the subject was documented.

B. Result

Table II. shows the best, the worst, and the average of 10 response times from each subject using both physical and mental commands to change the shape of the quadcopter. The last column shows the difference between the average times of physical and cognitive controls.

TABLE II. Comparing Average Response Times of Subjects

	Physical Command			**Mental Command**			
	Min (ms)	Max (ms)	Avg (10 times)	Min (ms)	Max (ms)	Avg (10 times)	Avg difference
Subject 1	485	1284	925.2	213	421	288.5	636.7
Subject 2	780	1095	943.7	226	519	312	631.7
Subject 3	510	1197	895.5	257	479	301.5	594

The average difference shows that using a cognitive command is twice as faster as using the physical counterpart, which means a user will have twice as much time to react with mental command than physical control in a critical morphing situation.

Similar experimentation using a car braking system with integrated BCI [11] had also captured and compared the time difference between physical and mental commands. According to Table III, the physical command between these two papers cannot be compared since each physical motion is different. However, the average response time between the two systems is similar even though the headsets are not the same for each experiment. It cannot be concluded that all the BCI headsets should have the exact same response times because there are other factors such as an unequal distance between the BCI sensor and receiver and processing speed for BCI commands. The data clearly shows that mental commands perform better than physical commands for both systems.

TABLE III. COMPARING AVERAGE RESPONSE TIMES OF MORPHING AND BRAKING SYSTEMS

	Physical Command			**Mental Command**		
	Min (ms)	Max (ms)	Avg (ms)	Min (ms)	Max (ms)	Avg (ms)
Morphing system	780	1495	921.47	213	519	268.32
Braking system	434	469	449.42	235	272	251.83
Difference in time	346	1026	472.05	22	247	48.84

VII. CONCLUSION

Users familiar with drones can be trained relatively easily to use the BCI integrated morphing quadcopter. All test subjects can change the quadcopter's morphology during a flight with mental commands and safely fly and land it. The response time of mental commands is faster than physical commands with all the subjects in this experiment and the referenced experiment. This time difference can be the deciding factor for the life of a morphing quadcopter while traversing narrow obstacles.

FUTURE WORK

Future improvements shall focus on adding more mental commands until inevitably replacing the RC transmitter with BCI mental commands for quadcopter movements such as pitch, roll, and yaw.

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