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Brain Computer Interface-Based Drone Control Using Gyroscopic Data From Head Movements

An Honors Thesis submitted in partial fulfillment of the requirements for Honors in
Computer Science

By
Ikaia Melton

Under the mentorship of Dr. Rocio Alba-Flores

ABSTRACT

This research explores the potential of using gyroscopic data from a person's head movement to control a DJI Tello quadcopter via a Brain-Computer Interface (BCI). In this study, over 100 gyroscopic recordings capturing the X, Y and Z columns (formally known as GyroX, GyroY, GyroZ) between 4 volunteers with the Emotiv Epoc X headset were collected. The Emotiv Epoc X data captured (left, right, still, and forward) head movements of each participant associated with the DJI Tello quadcopter navigation. The data underwent thorough processing and analysis, revealing distinctive patterns in charts using Microsoft Excel. A Python condition algorithm was then developed for the gyroscopic data interpretation to determine each head movement direction in addition to using the Tello drone commands derived from Tello SDK 2.0 User Guide Library. Real-time control was achieved by integrating a Python Lab Streaming Layer (LSL) for continuous data exchange between the Emotiv Epoc X and the Tello quadcopter. Experimental results affirm the successful control of the Tello quadcopter through gyroscopic data and head movements 98% accuracy run-time, showcasing the potential of this technology in drone control.

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Co-Thesis Mentor: Dr. Andrew Allen

Honors Dean: Dr. Steven Engel

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INTRODUCTION

In an era characterized by the intersection of human capabilities and advancing technology, the fusion of neurosciences, robotics, and artificial intelligence has forged a new frontier in human-machine interaction [1]. One promising avenue within this transformation is the development of Brain-Computer Interfaces (BCIs) tailored for controlling unmanned systems, notably drones. This study ventures into the realm of BCI-driven drone control, introducing an innovative method that harnesses the potential of a gyroscope sensor attached to the user's head to translate subtle head movements into precise navigational commands.

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have gained widespread utility across multiple domains, including surveillance, search and rescue missions, environmental monitoring, and leisure activities [2]. Despite their versatility, traditional methods of controlling these aircraft often demand a steep learning curve, limiting accessibility. Acknowledging this challenge, the integration of BCIs and head-mounted gyroscopes offers a pioneering approach to democratize drone piloting, enabling individuals to maneuver these aerial platforms effortlessly through cognitive intent and minimal head movements. The primary drive behind this exploration is to narrow the gap between human intention and machine execution by investigating the feasibility and effectiveness of using a gyroscope sensor fixed on the user's head as an intuitive and efficient drone control mechanism.

In this study, the focal Unmanned Aerial Vehicle (UAV) is the DJI Tello quadcopter, which has dimensions 98×92.5×41 mm, and weighs only 80 g shown in Fig. 1. It uses a lithium ion, 1.1Ah/3.8V, battery that provides about 13 min of flight time. This drone is programmable using the Tello SDK which allows a connection to the drone using a Wi-Fi port. The DJI Tello quadcopter in this project operated through a Brain-Computer Interface (BCI) utilizing its gyroscopic data to perform simple tasks controlled by the user's head gestures (left, right, still and forward). The gyroscope, functioning as a precision sensor for measuring and maintaining orientation, plays a critical role for interpreting head movements captured by the Emotiv Epoc X headset using gyroscopes.

The gyroscope columns X, Y and Z have data (formally known as the GyroX, GyroY, GyroZ) that indicate a numeral direction head is position. These measurements, encompassing tilt, rotation, and angular velocity, constitute the foundation for translating head gestures into commands for drone control via the Brain-Computer Interface (BCI) system. The seamless integration of BCI technologies and gyroscopic data as explored in this research aims to empower users with unparalleled precision and responsiveness in navigating drones. The study investigates the development and evaluation of a Brain-Computer Interface for a quadcopter control system, emphasizing the fusion of neurotechnology and gyroscope advancements [3]. It scrutinizes hardware and software components, exploring potential applications and implications within the realm of assistive technology, human-computer interaction, and beyond. The goal is to create an interface that empowers users to navigate drones with unparalleled precision, responsiveness, and ease.

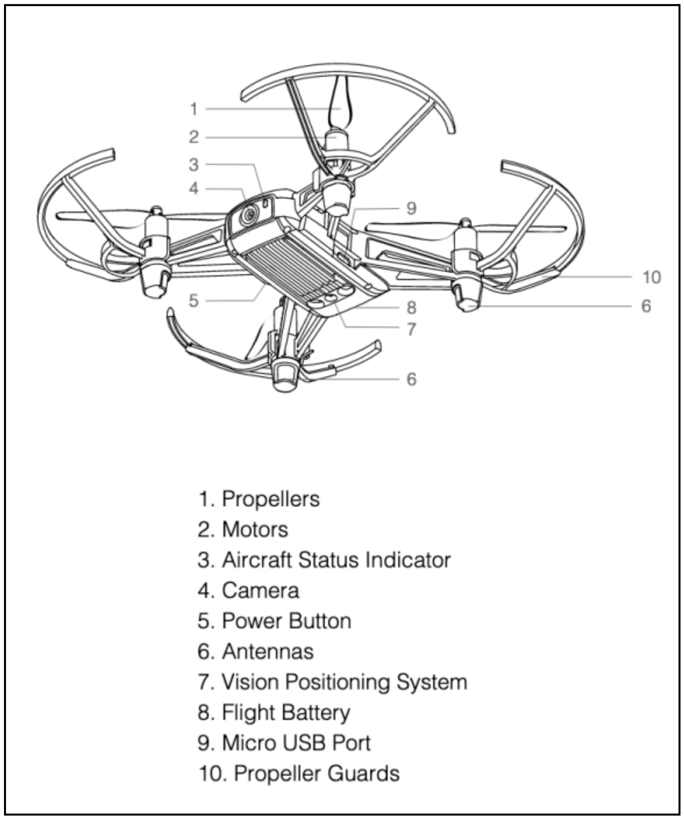

Figure 1. DJI Tello Quadcopter UAV with the principal components of the drone depicted above.

LITERATURE REVIEW

The field of Brain-Computer Interface (BCI) technology has witnessed notable applications using gyroscopes, marking a paradigm shift in human-machine interaction. This literature review offers a comprehensive survey of current research endeavors focusing on the utilization of BCI technology for gyroscope application control. It delves into the methodologies employed, the outcomes achieved, and the vast potential applications within this technological domain. In a study, Gerardo Rosas-Cholula. (2013)

used a similar approach to showcase the application of BCI for cursor control, mimicking conventional computer-mouse operations. This innovative approach integrates gyroscope and eye-blinking electromyographic signals, harnessed through a cutting-edge 16-electrode wireless headset from Emotiv. The study successfully achieves cursor manipulation through gyroscope data and employs a detection procedure based on Empirical Mode Decomposition (EMD), yielding an impressive average detection rate of 94.9% [4].

Another study by Yiwen Jiang. (2021), introduces a novel head position monitoring and classification system. This system employs thin, flexible strain sensing threads positioned on the neck, and a wireless circuit module for recording and transmitting strain information to a computer. Leveraging a sophisticated data processing algorithm, the system offers near real-time quantification of head position. A battery of classifiers, including Support Vector Machine, Naive Bayes, and KNN, achieves a remarkable testing accuracy of around 92% for nine distinct head orientations, affirming the accuracy, flexibility, ease of use, and cost-effectiveness of this human-machine interface platform [5]. Overall, the reviewed studies underscore the potential efficacy of BCI technology in gyroscope application control across diverse environments. However, the precision and reliability of control hinge on the quality of recorded signals and the intricacy of the control task.

This prompts the need for further research to unravel the extensive applications of this technology in realms across different fields due to their ability to measure and maintain orientation and angular velocity. The intersection of BCI and gyroscope application control presents an exciting frontier, promising transformative advancements in human-machine collaboration.

EMOTIV PRO X HEADSET

The Emotiv Epoc X is a 14-channel portable EEG system shown in Fig 2, [6]. The fourteen channels of EEG signals are recorded from AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4. In addition to the 14 electrodes the EEG neuroheadset contains a three-axis gyroscope columns X, Y and Z (formally known as GyroX, GyroY, GyroZ) that allows tracking of head movement. These data are recorded into an computer application called EmotivPRO. The EmotivePRO application captures research-grade raw data from the Emotiv Epoc X headset at 256 samples per second. This study focuses on the use of data collected from the three-axis gyroscope columns to determine the head movements of the subject. The EEG signals were not employed in this analysis.

Furthermore, in this research, the Emotiv Epoc X gyroscope was placed on the frontal cortex of each of the 4 participants. The data collected from the gyroscope were arranged in 3 columns: GyroX, GyroY, and GyroZ. These three axes are used in capturing gyroscope data via the Emotiv Epoc X headset. Each axis corresponds to a specific dimension of rotational movement. GyroX–primarily registers movements along the horizontal axis, enabling detection of head tilts to the left or right. Meanwhile, GyroY–associated with movements along the vertical axis, allows the headset to detect nods of the head, whether upwards or downwards. Lastly, GyroZ– captures twisting or rotational movements around an axis, facilitating the detection of head turns from side to side. These axes collectively provide a comprehensive means to track and interpret diverse head movements, forming the basis for various applications in user interaction and control systems.

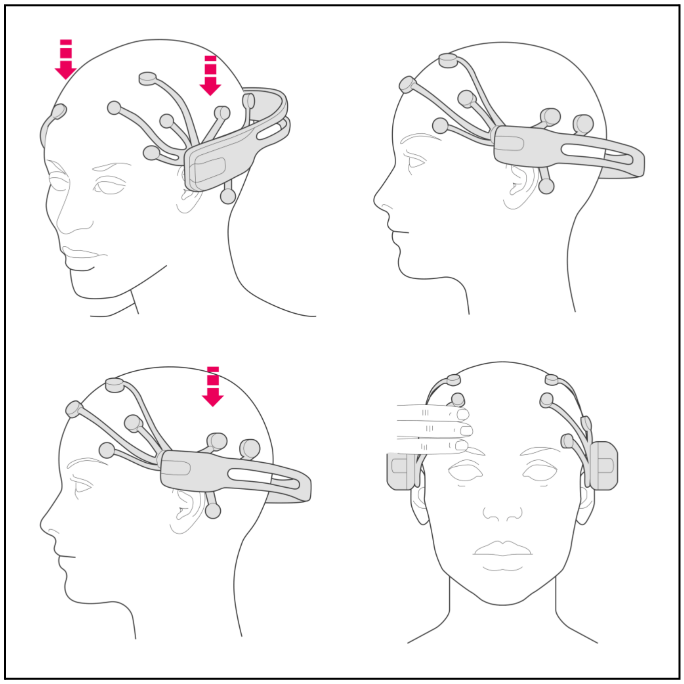

Figure 2. EMOTIV EPOC X 14 channel mobile brainware on a participant's head in four different angels that consisted throughout the study.

DATA COLLECTION AND FEATURE EXTRACTION

The Emotiv Epro X software, Emotiv PRO, collects gyroscopic data from the X, Y, Z columns (formally known as GyroX, GyroY, and GyroZ) by recording the motion sensors from the headset. It then utilizes the Lab Streaming Layer (LSL) on the EmotivPRO software to manage and transmit data streams from the Emotiv Epoc X headset. LSL standardizes and synchronizes the gyroscope data, packaging it into matrices. Matrices are a rectangular array or table of numbers arranged in rows and columns, which is used to represent a mathematical object or a property of such an object. In this case, the formatted data is too big to classify all at once during the drone take-off so a feature extraction would have to be performed. Feature extraction refers to the process of transforming raw data into numerical features that can be processed while preserving the information in the original data set. The feature extraction was performed using a python coding language for the research. A sample of the python code is shown below:

```
# The following deletes the columns of the matrix to get towards a certain
motion sensor column, gyroscope data.
    data.append(sample)
    del data[x][12]
    del data[x][11]
    del data[x][10]
    del data[x][9]
    del data[x][8]
    del data[x][7]
    del data[x][2]
    del data[x][1]
    del data[x][0]
    # x serves as a counter for the program to terminate at 100 samples (adjust as
needed)
    x = x+1
```

```
#modify x number to no of samples for 3 seconds
if(x>100):
    #The Functions for classifying head movements
    # Initialize i to start at 0
    # Dividing the Gyroscope into different matrices
    i = 0
    data0=data[0][0]
    data1=data[0][1]
    data2=data[0][2]
    data3=data[0][3]
```

This was done on a py.file once transmitted in real-time to an external integrated development environment (IDE) platform. In this study, PyCharm was used to receive and process the continuous stream of data to run, analyze and interpret. The process of gathering gyroscope signals involved volunteers executing specific head gestures—left, right, still, and forward. Each deliberate gesture lasted 3.1 seconds, followed by a 2-second rest period. The gyroscope data capturing commenced, recording signals generated during each head gesture. Each recording spanned 30 seconds for each distinct head movement resulting in comprehensive datasets.

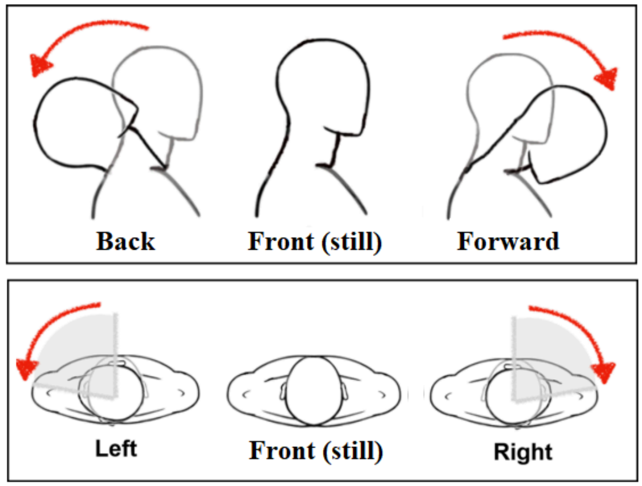

Figure 3. Illustration of the head movements used in this research.

The python script selectively isolates and extracts relevant information from the gyroscopic signals. This crucial feature extraction phase sieved through the dataset, laying the groundwork for subsequent in-depth analysis and classification. This meticulous process of capturing, organizing, and extracting data served as the foundation for the comprehensive analysis aimed at decoding and categorizing intricate head movements. The systematic approach during data collection and extraction set the stage for a thorough examination, crucial for subsequent stages of algorithm development and system refinement. Moreover, upon collecting and classifying the movements, there were notable similarities and differences between each head motion that was performed which is indicated in the Microsoft Excel data chart Fig 4. The data collected are the mean average of each gyroscopic column sample X, Y, and Z of each of the participants. There were also distinct patterns in a graph Fig 5 by the participants after calibrating the headset, their data was similar to another person's head performing the same action.

	GyroX	GyroY	GyroZ
PersonA.Still	0.43	0.39	-0.58
PersonA.Right	0.66	0.44	-0.17
PersonA.Left	0.49	0.58	-0.56
PersonA.Back	0.67	0.59	-0.26
PersonA.Forwar	0.5	0.44	-0.51
	GyroX	GyroY	GyroZ
PersonB.Still	0.43	0.39	-0.58
PersonB.Right	0.64	0.42	-0.17
PersonB.Left	0.5	0.67	-0.52
PersonB.Back	0.66	0.56	-0.32
PersonB.Forwar	0.51	0.42	-0.55

Figure 4. A chart of two individuals full-complete analysis (recorded each 20 times) average data for the 3 gyroscopic data columns GyroX, GyroY, and GyroZ.

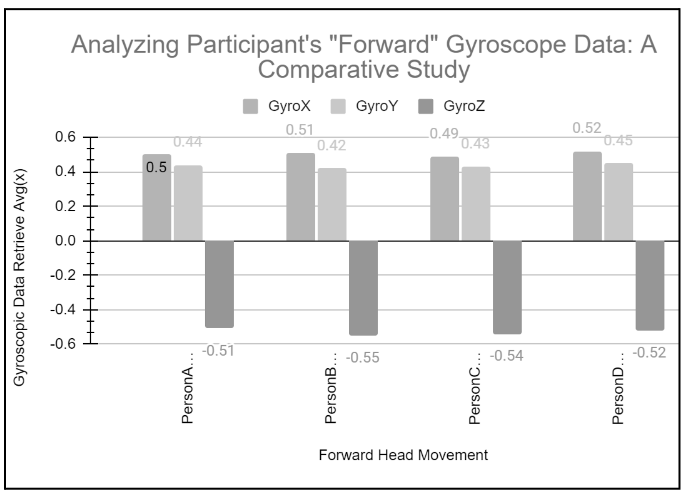

Figure 5. A graph of the four individuals and their averages for GyroX, GyroY, GyroZ for the head movement "Forward".

PYTHON ALGORITHM

To comprehend and classify the distinct head movements left, right, still and forward detected by the gyroscope sensor of the Emotiv Epoc X headset, an extensive analysis predominantly focused on the Gyroscope columns, primarily GyroX, was conducted. The primary goal was to delineate distinct motions: left, right, still, and forward. To commence this exploration, a comprehensive analysis aimed to establish average values representing each head movement within GyroX. These numerical findings formed the foundation for meticulous use of Microsoft Excel's tools for visual representation. The resulting patterns illustrated unique signatures for each head movement, facilitating easy differentiation and identification. Transitioning to Python programming, these discerned patterns were translated into if-else conditional statements. These statements became pivotal in the program's decision-making process, enabling real-time identification and classification of ongoing head movements based on the gathered data. The apex of this effort lay in integrating this classification framework with drone control [7]. Through Python scripting, the program seamlessly incorporated precise drone commands, derived from the Tello Drone 2.0 SDK from the User Guide library, for accurate motion capturing. Consequently, upon detecting predefined head movement conditions, the quadcopter executed corresponding maneuvers, establishing a seamless synchronization between human gestures and the quadcopter actions.

Once classified, in PyCharm, the IDE for python, the code to classify the head motions output was Tello Drone commands imports to see in real-time the data captured while LSL ran. A sample of the code is shown below:

```
# Call the identify_head_movement function with the appropriate data values
        if 0.70 <= data0 <= 0.99:
            print(data0)
            print("Left Head Movement")
```

```
    drone.move_left(40)
elif 0.40 <= data0 <= 0.90: #and 0.10 <= data1 <= 0.25:
    print(data0)
    print(data1)
    print (data2)
    print("Forward Head Movement")
    drone.move_forward(40)
elif 0.01 <= data0 <= 0.40:
    print(data0)
    print("Right Head Movement")
    drone.move_right(40)
     else:
    print(data0)
    print("Still")
    # prints whole matrix
    #print(data, 'n/')
    # prints second value of the first row in the matrix
#print(data)
# have it classify the head movement and send drone command here
x=0 # resetting the counter and the recording
data=[]
# breaks the loop and terminates the program
```

```
        continue# replace the break with a continue

        # The Functions for classifying head movements
drone.land()
```

RESULTS

In this research, diverse head movements—left, right, still, and forward—were systematically captured and processed. Volunteers executed these gestures for 30 seconds each, contributing to a comprehensive dataset. The results indicate an impressive 98% accuracy in real-time drone flight synchronization with head movements. The Python algorithm, featuring a sophisticated if-else conditional statement, seamlessly translates interpreted head movements into precise command signals, successfully controlling the Tello drone in real time. These findings affirm the success of our project, showcasing the seamless control of the drone through a curated set of four head movements. This represents a significant advancement in real-time drone control through Brain-Computer Interface integration.

CONCLUSION AND FUTURE WORK

During the development of this research, various challenges surfaced, offering substantial insights and avenues for future improvements. One significant hurdle revolved around accurately collecting Gyroscope data from individuals. Initial endeavors to capture this data yielded diverse values within the GyroX, GyroY, and GyroZ columns, resulting in unexpected fluctuations and inconsistencies.

Furthermore, while programming the drone to react to distinct head movements, unexpected behaviors surfaced. Despite expectations of the drone responding to specific head gestures with corresponding flight patterns, it frequently exhibited contrary movements or remained stationary.

Upon extensive investigation, it became evident that calibration played a pivotal role in ensuring the drone's accurate response. However, the need for recalibration every time a user interacted with the drone posed logistical challenges, particularly for individuals with mobility constraints, such as those using wheelchairs [8]. This underscored the necessity for a smoother calibration process that wouldn't hinder the user experience.

Additionally, the incorporation of backward head movements introduced complexities, leading to intricate identification issues and impacting the drone's response to other gestures. Notably, the variations in backward head positioning among individuals, even within standardized parameters, further complicated the consistency of the drone's interpretation. Despite multiple testing phases, addressing the challenge posed by backward head movements remains an ongoing endeavor. The research is focused on refining and resolving these issues to ensure a more comprehensive and dependable system.

Looking ahead, this research demands sustained efforts to tackle and overcome the complexities associated with backward head movements. Improvements in calibration methods and establishing a robust baseline for diverse head positions stand as crucial areas for further exploration and refinement. These efforts aim to establish a more inclusive and accurate framework for drone control based on head gestures, ultimately fostering a smoother and more accessible human-machine interaction.

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