Combining Mindwave, MPU6050, internet of things for reliable safe monitored wheelchair control system

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ABSTRACT

This paper proposes the development of a wheelchair control system by combining a Mindwave electroencephalogram (EEG) sensor, an MPU6050 inertial sensor, an ultrasonic sensor, and internet of things (IoT) technology. Stroke survivors often face challenges in controlling their wheelchairs due to cognitive and physical impairments, requiring specific solutions to ensure their safety and comfort. The integration of the Mindwave EEG sensor captures the user's cognitive state, such as level of attention and focus, while the MPU6050's inertial sensor monitors physical movement and changes in head orientation. Additionally, the ultrasonic sensor is incorporated to detect obstacles and provide proximity information for safe navigation. This wheelchair control system is also linked with IoT technology to enable monitoring of the user's cognitive, physical and environmental condition, and remote assistance. In this paper, to implement this wheelchair control system, a T-BEAM with an ESP32 controller is used, which is equipped with GPS to provide wheelchair location data and LORA radio communication for remote data transmission, and a TTGO LORA32 to forward the data to Arduino IoT cloud service over Wi-Fi. The results of the development show that the wheelchair control system is safer and more monitored, and users are easier and more flexible in operating wheelchairs.

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1. INTRODUCTION

Recently there have been various kinds of technologies that help assist physically disabled people. This control system is specifically designed to assist those with physical limitations. This competitive system replaces the conventional manual assist system. One of the technologies that greatly assist people with disabilities is the electric wheelchair. To assist individuals with severe paralysis, an electric wheelchair has been developed that can be controlled solely using brainwave signals. However, the equipment required to create brainwave-controlled electric wheelchair is still expensive.

In recent years, a brain-computer interface (BCI) device called Neurosky Mindwave Mobile 2 has been introduced to the market at an affordable price. Neurosky Mindwave Mobile 2 is an electroencephalography (EEG) unit. Numerous studies have been conducted to implement the control of electric wheelchairs using Mindwave [1]–[9]. However, the results of implementing control with Mindwave are still unreliable. Even with the addition of control algorithms such as neural networks, machine learning (ML) techniques like support vector machine (SVM), and other advanced programming methods, reliable control has not yet been achieved [10]–[12]. This is partly due to the variability of brainwave patterns and Mindwave's limitation to reading only physical brainwave signals, unable to access the actual thoughts within the brain. Several studies have also indicated that controlling an electric wheelchair with Mindwave alone is not reliable and accurate without the addition of other sensors [13]–[16].

The following are several alternative methods of controlling electric wheelchairs. The first alternative for controlling an electric wheelchair has emerged using the eye blink. However, the disadvantage of eye blinks-primarily based manipulation is that customers frequently experience uncomfortable, their imagination and prescience is barely impaired, and studying errors often appear because of reflexive and unintentional blinking [17]–[21]. Another alternative is to use a camera placed in front of the wheelchair to detect head movements. Although this affords more flexibility and luxury for the consumer without additional equipment, the technology is still expensive [22]–[28]. Furthermore, because of the usage of a camera, studying mistakes can arise because of adjustments in lights and roles as a consequence of wheelchair vibrations [29]–[31]. Another alternative is the use of voice control [32]–[34]. While voice control allows for more reliable control of electric wheelchairs, voice control cannot used by stroke patients have difficulty speaking.

By comparing the advantages and disadvantages of various alternative control methods for stroke patients mentioned above, this study proposes the use of a combination of Mindwave and MPU6050. Why use the combination of Mindwave and MPU6050? Because they can complement each other to meet the needs of individuals with disabilities, especially stroke patients. The combination of Mindwave and MPU6050 allows for a more robust and accurate control of the wheelchair. More about how the proposed system works and research methods and results can be seen in the following sections. The paper is organized as follows: section 2 illustrates the hardware and software of the development system, which used in this study. Section 3 addressed the results and discussion, while section 4 concludes this study.

2. METHOD (PROPOSED SYSTEM)

This study proposes the use of a combination of Mindwave and MPU6050 to develop a reliable, fast response, and comfortable wheelchair control system. Since head movements play a significant role, Mindwave is needed as a safety measure. By using Mindwave, three sets of data are obtained: sensor reading quality, meditation level, and attention level. Safety measures are implemented by allowing the wheelchair motor to be activated only when the attention level exceeds 70. This value ensures that the passenger has sufficient alertness to anticipate any undesired conditions. The meditation level data can indicate a person's drowsiness level. The higher the meditation level, the more likely the person is feeling drowsy. When the meditation level exceeds 90, the wheelchair motor turns off. The sensor reading quality and meditation level data are used to deactivate the wheelchair motor. When the passenger removes the sensor or loosens it by raising their eyebrows, the wheelchair motor turns off. In addition to Mindwave and MPU6050 combination, an ultrasonic sensor is added for enhanced safety. Ultrasonic sensor detects objects in front of the wheelchair, and if an object is detected within a distance of less than 1 meter, the wheelchair automatically stops and activates a buzzer. In addition, the wheelchair can only be operated when the passenger's alertness level is sufficiently high, and the direction can be controlled by simply moving the head slightly forward, right, left, or backward. Furthermore, to provide an alternative control device, a joystick is also included alongside Mindwave and MPU6050. The joystick can be used to move the wheelchair forward, backward, left, or right by simply manipulating the lever. To avoid interference, the joystick control can only be used when Mindwave headset is removed. When Mindwave headset is worn on the head, the wheelchair is controlled using Mindwave and MPU6050. If Mindwave headset is removed, the wheelchair is controlled using the joystick.

2.1. Hardware structure

Starting with the mechanical construction, Figure 1 shows the prototype of electric wheelchair equipped with a universal joystick. The manual wheelchair has been modified with the addition of a direct current (DC) motor unit on both wheels which is connected to an electrical circuit in the joystick box. The DC motor used is a 24 V PG56 16 rpm 500 kgfcm 7 ppr encoder breaking. As a power source, a 24 V 12 Ah Lithium-Ion battery is added. This prototype has dimensions of 1,060×680×940 millimeters. This prototype has been tested and is able to carry a maximum passenger load of 120 kg. This wheelchair uses materials from mild steel pipes which are coated with paint protection.

2.2. Software structure (electric and program)

This section is the core of the system developed, namely the electrical components and program. Mindwave is the main electrical component, followed by the MPU6050 inertial sensor. Moreover, for healthcare purposes, the physical condition data of the passenger is monitored and stored in the IoT cloud for further analysis as studied in [35]–[37]. This includes data on the level of alertness, meditation level, head movement direction, wheelchair location, wheelchair speed, and other physical data. To accommodate the proposed features, Figure 2 shows the block diagram of the wheelchair control system design that combines Mindwave, MPU6050, ultrasonic sensor, and IoT technology.

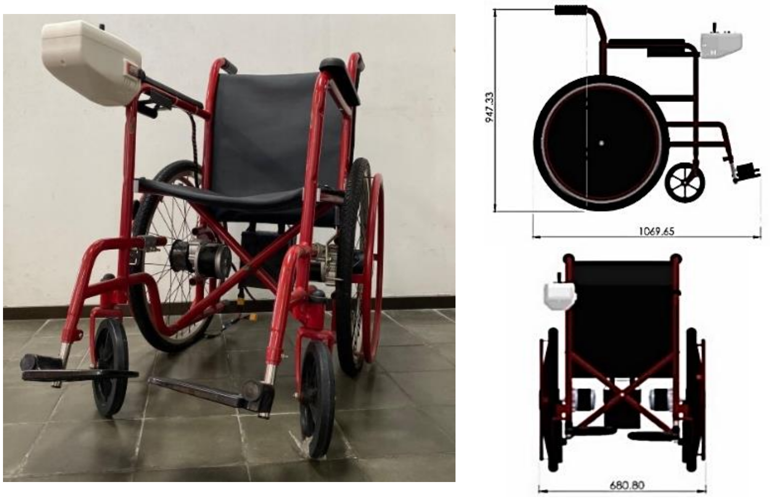


Figure 1. Prototype of electric wheelchair with joystick, DC motors, and 24 V battery

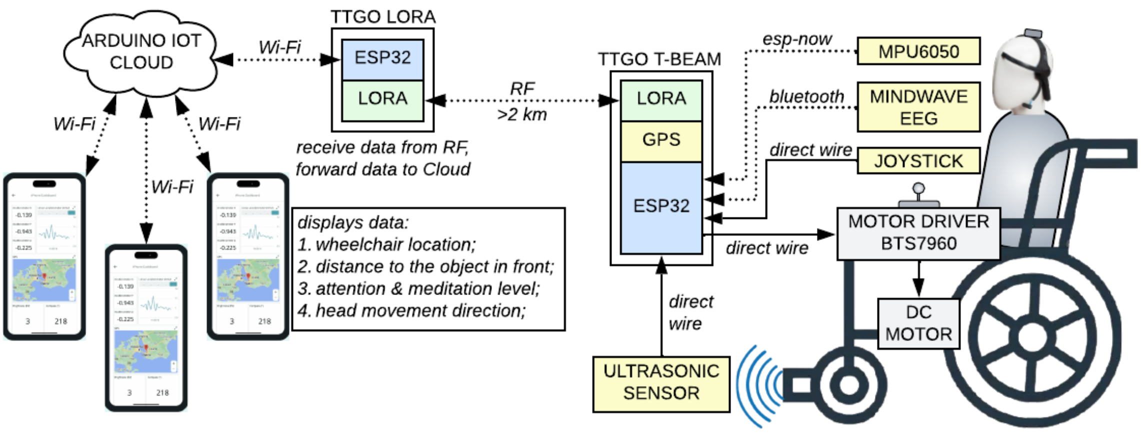


Figure 2. Block diagram of the wheelchair control system

Figure 3 is the flowchart for the block diagram of electric wheelchair control system that combines Mindwave, MPU6050, Ultrasonic sensor and IoT technology. The first part is the main program flowchart of the wheelchair control system Figure 3(a); while the next is the program flow for Mindwave Figure 3(b); for MPU6050 Figure 3(c), for Joystick Figure 3(d), and for IoT Figure 3(e). After the wheelchair hardware has been installed, the next step is to make the control circuit and program the microcontroller.

The following Figure 4 illustrates the entire wheelchair control system, which involves three separate circuits. The first circuit involves the Mindwave, ESP-01, MPU6050 and battery. The second circuit involves the T-BEAM, OLED, joystick, ultrasonic sensor, BTS7960 motor drivers, DC motors, and battery. The third circuit involves TTGO-LORA32 and battery. The first circuit functions to transmit brain signal data and head position to the T-BEAM microcontroller in the second circuit. In the second circuit, brain signal, head position, joystick, and ultrasonic sensor are combined to control the direction and movement of the wheelchair through a DC motor with BTS7960. The third circuit is used to transmit brain sensor data, head position, location, direction, and wheelchair speed to the Cloud with the help of Arduino IoT cloud.

Figure 5 shows the actual components used, including T-BEAM, TTGO-LORA-ESP32, joystick, ultrasonic sensor, Neurosky Mindwave Mobile 2, with an MPU6050 sensor and ESP-01 attached on top. For the IoT technology used, Arduino IoT cloud is utilized here, because it has many interesting features, one of which is that it can be accessed with a smartphone, and the data can be displayed on the IoT cloud Dashboard and Google Sheets.

The devices in Figure 5 are interconnected wirelessly, except for Joystick and Ultrasonic sensor, which are directly connected to T-BEAM using cables. Here, T-BEAM is placed on the wheelchair, which will read the values of all sensors, including Mindwave, MPU6050, ultrasonic sensor, joystick, and GPS. Mindwave sensor data is transmitted to T-BEAM via Bluetooth. MPU6050 sensor data is sent by ESP8266-01 to T-BEAM via Wi-Fi using ESP-NOW. The sensor data read by T-BEAM is then transmitted to TTGO LORA ESP32 via LORA radio communication. Furthermore, from TTGO LORA ESP32, the received data is sent to Arduino IoT cloud.

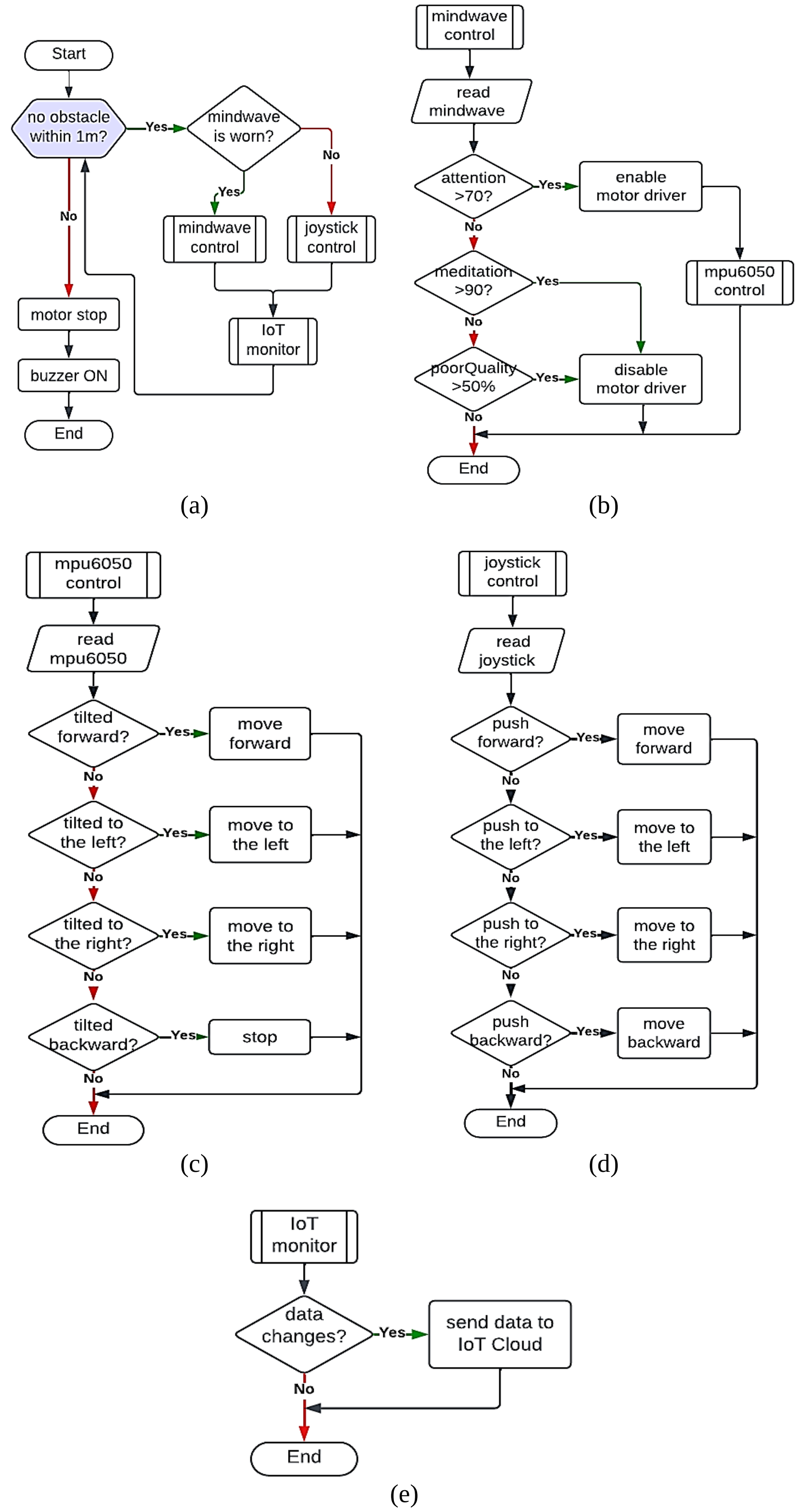


Figure 3. Flowchart of: (a) main program, (b) Mindwave program, (c) MPU6050 program, (d) joystick program, and (e) IoT program

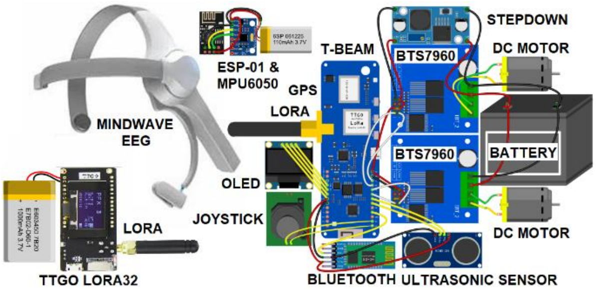


Figure 4. The circuit of electric components of the wheelchair control system

Figure 5. Components or devices used in the electric wheelchair control system, including Arduino IoT cloud

3. RESULTS AND DISCUSSION

In accordance with the design of the control system in Figure 1, an electric wheelchair control device combining Mindwave, MPU6050, ultrasonic sensor and GPS has been successfully implemented. Figure 6 shows how the communication between T-BEAM and TTGO LORA ESP32 has been successfully established. Figure 6(a) displays the sensor data read by T-BEAM and shown on the T-BEAM's OLED. Figure 6(b) displays the sensor data transmitted by T-BEAM and displayed on the OLED of the TTGO LORA ESP32. These displays sequentially present data from Mindwave, MPU6050 and GPS. From the Mindwave, the displayed data includes connection quality, attention, and meditation level. From the MPU6050, the displayed data includes head position and movement. From the GPS, the displayed data includes latitude and longitude coordinates, movement, and speed of the wheelchair where this GPS is placed.

Figure 7 shows the display of data on the Arduino IoT cloud dashboard, which is sent by the TTGO LORA ESP32. The data is presented in the form of box widgets. There are five box widgets in total. The first widget displays Mindwave sensor data. The second widget displays the wheelchair direction data, which is obtained from head movement. The third and fourth widgets display MPU6050 sensor data. The fifth widget displays the location data read by the GPS.

(a) (b)

Figure 6. How the sensor data read by T-BEAM' are displayed on (a) the OLED on T-BEAM and (b) the OLED on TTGO LORA ESP32

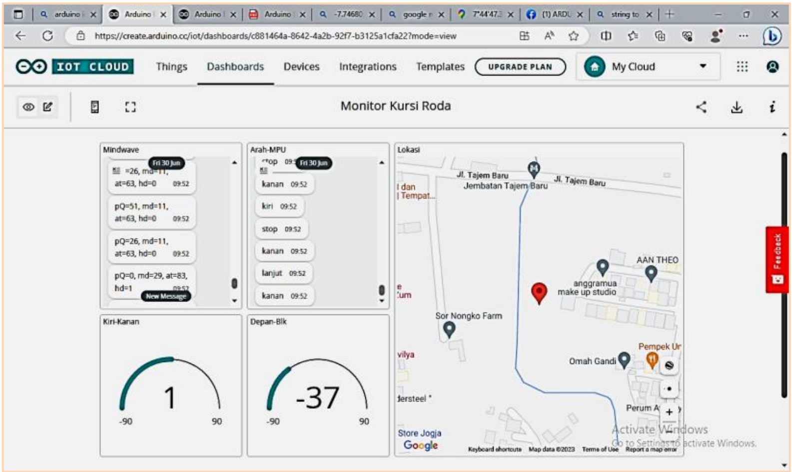
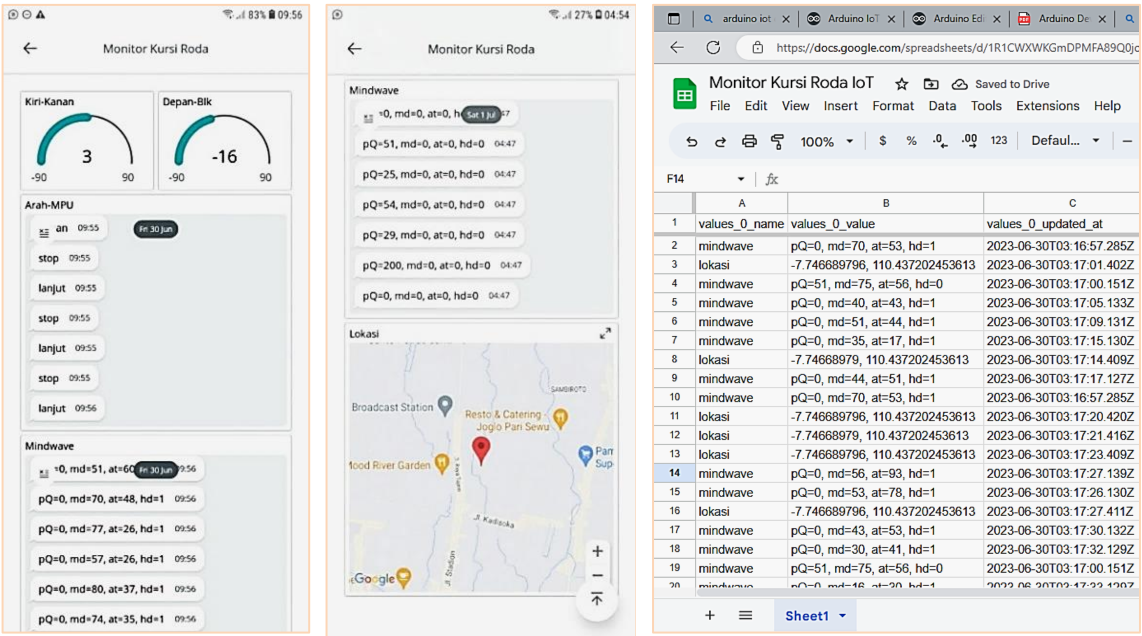


Figure 7. Dashboard of Arduino IoT cloud displays Mindwave, MPU6050 and GPS sensor data

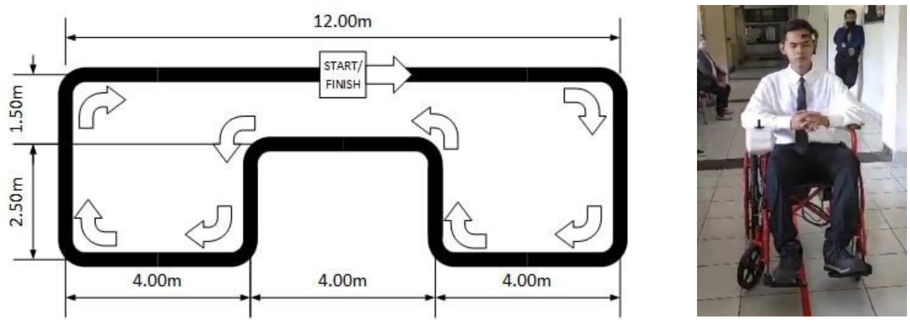
By using Arduino IoT cloud, the sensor data displayed on the Dashboard can be accessed from a smartphone and Google Sheets with the help of Webhook. By having the sensor data displayed in Google Sheets, data processing becomes easier as the data is recorded continuously, allowing for analysis to observe trends over time. Figure 8 shows the display of sensor data on a smartphone Figure 8(a) and in Google Sheets Figure 8(b).



(a) (b)

Figure 8. The sensor data: (a) display on smartphone and (b) display in Google Sheets

To ensure that this developed wheelchair control is truly reliable, easy to operate, safe, and comfortable during maneuvering, testing was conducted on 5 individuals with varying ages and genders. Each person was instructed to operate the wheelchair following a winding path. The first test involved using a joystick, while the second test involved using Mindwave+MPU6050. Each person was informed that when using the joystick, the wheelchair would move according to the direction of the lever and stop when the lever is in the middle position. When using Mindwave+MPU6050, the wheelchair would move forward if the attention level is above 70% and the person nods their head. The wheelchair would move left if the person tilts their head to the left and move right if the person tilts their head to the right. The wheelchair would stop if the person raises their eyebrows. Figure 9 shows how the testing was conducted. Figure 9(a) displays the path that the wheelchair needs to traverse. Figure 9(b) shows a photo of one of the participants in the second test operating the wheelchair following the path using Mindwave and MPU6050.



(a) (b)

Figure 9. How the wheelchair testing was conducted (a) wheelchair testing path and (b) a photo of a participant during the second test

The testing was conducted by asking each person to operate the electric wheelchair following the track for a total of 5 full rounds for the joystick control, and another 5 rounds for the Mindwave+MPU6050 control. By comparing the time required to complete 1 full round at the same speed, which was set at 5 km/h, it can be determined whether the operation of the wheelchair is classified as easy or difficult. Of course, the less time required to complete 1 round, indicating less deviation, indicating that the operation of the wheelchair is relatively easy. Conversely, the longer it takes, it can be said that the operation of the wheelchair is classified as difficult. The test result time data required for the joystick control can be seen in Table 1. The test result time data required for the Mindwave+MPU6050 control can be seen in Table 2.

Table 1. Test result time data required for controlling the electric wheelchair with joystick

Subject	Test1	Test2	Test3	Test4	Test5	Average
A	45	39	42	41	36	40.6
B	37	36	36	36	36	36.2
C	38	41	38	33	31	36.2
D	43	42	32	35	33	37
E	45	45	42	37	33	40.4
Average						**38.08**

Table 2. Test result time data required for controlling the electric wheelchair with Mindwave+MPU6050

Subject	Test1	Test2	Test3	Test4	Test5	Average
A	57	58	56	47	42	52
B	57	50	53	52	45	51.4
C	50	51	41	43	41	45.2
D	52	46	49	48	43	47.6
E	57	50	46	42	43	47.6
Average						**48.76**

From the test results Tables 1 and 2, it can be said that control with the joystick is easier compared to the Mindwave+MPU6050. This can be understood because, in general, hand movements are easier to control compared to head movements. However, even though it is considered more difficult than the joystick, from the test results, it is known that the Mindwave+MPU6050 control is reliable enough, as evidenced by everyone being able to successfully complete the track 5 times. Control with Mindwave+MPU6050 is quite challenging when it comes to turning, as it requires adjusting how long the head should be tilted to make the wheelchair turn in the right direction. From the test results table, it is also known that the time required for subsequent tracks decreases over time, as everyone has become accustomed and trained in operating this electric wheelchair.

The discussion results from this study can be summarized as shown in Table 3. The results are still not reliable if only apply Mindwave control. Robust control is not achieved by adding control algorithms, for example neural networks and machine learning or other programming methods. The use of eye blinking has its drawbacks, users often feel uncomfortable, their imagination and awareness are slightly disturbed, and learning errors are often caused by reflexive and unintentional blinking. Control by using a camera to detect head movement, the weakness is in the factor of lighting disturbance and wheelchair vibration. While voice control may be more reliable, but it cannot be used by stroke patients who have difficulty speaking.

Table 3. The results of previous works compared with this study

References	Method	Results
[1], [9], [14], [16]	- Reading attention level and meditation level with Mindwave - Providing specific treatments to shape brain signal patterns	- less accurate - less responsive
[3], [6], [10], [13], [20]	- Reading attention level, signal quality, and blinking with Mindwave - Wheelchair operated with attention level, while direction of movement is determined by blinking	- less accurate - less responsive - eyes get tired
[4], [5], [11], [15]	- Reading raw EEG signals with Mindwave - Data processing with neural networks and/or fuzzy logic	- less accurate - less responsive - requires multiple training
[8], [12], [15], [17]	- Reading brain signals and eye movements with EEG devices other than Mindwave (Emotiv EPOC, Active Two System) - Using more electrodes (Emotiv EPOC uses 14 electrodes, Active Two System uses 32 electrodes) to obtain deeper and more complex brain analysis - Data processing with neural networks and/or fuzzy logic	- less accurate - less responsive - requires complicated calibration - requires multiple training
[18], [28], [30]	- Capturing eye movements, or facial expressions with a camera - Data processing with neural networks and/or fuzzy logic	- less accurate - too sensitive to light and vibrations
[19]	- Capturing eye movements and blinking with OpenBCI - Adding sound signals as cues, allowing for more command variations with limited eye movement input - Data processing with neural networks and/or fuzzy logic	- less accurate - too sensitive to light and vibrations - eyes get tired
[32]–[34]	- Capturing and recognizing sound - Wheelchair control using sound - Data processing with neural networks and/or fuzzy logic	- less accurate - less sensitive - requires multiple training
[21]–[29]	- Reading head movements with acceleration and/or orientation sensors (Tilt sensor, ADXL330, MPU6050, BNO055) - Wheelchair movement follows head movements	- more responsive - too sensitive to vibrations - head movement restricted
This study	- Combining Mindwave with MPU6050 sensor - On/off control of the wheelchair based on readings of attention level, meditation level, and signal quality from Mindwave, while wheelchair movement direction is based on readings from MPU6050, which are only read once when the threshold value is exceeded	- more accurate - more responsive - head can move more freely

4. CONCLUSION

From the above test results, it can be concluded that the integration of Mindwave and MPU6050 has successfully created a reliable control system for the electric wheelchair. Furthermore, combining Mindwave and MPU6050 is crucial for safe wheelchair control as it allows for a comprehensive understanding of the user's cognitive and physical state. By integrating these sensors, the wheelchair control system can accurately interpret the user's intentions, filter out unintended movements, adapt to changes in the user's abilities, and provide real-time feedback to ensure a safe and reliable wheelchair navigation experience. The addition of ultrasonic sensors also enhances safety, both for the user and for others in the vicinity. Lastly, with the addition of the Arduino IoT cloud, user condition data, attention level, drowsiness level, wheelchair speed, location and movement can be monitored over time and stored in Google Sheets, which can be utilized for healthcare purposes for wheelchair users.

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