Speed Control of a Wheelchair Prototype Driven by a DC Motor Through Real EEG Brain Signals

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Abstract. For some disabled people, Electroencephalogram (EEG) signals are used to interpret brain thinking to drive machines by creating interface between the human brain and such machines. EEG signals are naturally varied due to human thinking process, and can be manipulated to drive a wheelchair based DC motors in real-time without any muscular efforts. In this paper, EEG signals are used to control DC motors using a Brain Computer Interface (BCI) that includes an EEG sensor headset to capture brain signals. The extracted EEG signals are considered as reference signals and transmitted to a microcontroller via Bluetooth. An intelligent wheelchair (IW) with an EEG sensors is connected to an Arduino, that drives two DC motors, to control movement references to the specific EEG signals. For the proposed IW based EEG, life cycle cost (LCC), over 5 year lifetime, is about 2674$ compared with a manufactured passive wheelchair, which its LCC is 3957$. The experimental tests suggest that the proposed design of IW is efficient and low cost as well as allowing disabled people to more easily control their wheelchairs and to lead independent lives.

1. Introduction
Due to increases in the number of traffic accidents, aging populations, and some Poliomyelitis diseases, it has been noted significant growing needs for easy control to speed and direction of disabled wheelchair. Manual or electric wheelchairs are very important in everyday life for those with limited lower body mobility. Most traditional electric wheelchairs are designed to be controlled in terms of speed and direction by using joysticks; however, some disabled people, particularly those with severe vascular accident in brain stem, who completely lost their hands, or of spinal cord damage remain in muscular paralysis. Although such people retain all of their cognitive faculties, they cannot communicate easily with those around them and then it will be difficult to be assisted. To address such problems, an alternative wheelchair could be developed to enable those of severe disability to lead the wheelchair easily by brain signals.

Brain signals are an essential factor in the design of an intelligent system for controlling wheelchairs to achieve an Intelligent Wheelchair. There are different kinds of brain signals and these are dependent on human attention and meditation levels, and the threshold values for the brain signals should be set in such a way to navigate direction degree and speed of the wheelchair accurately. Signals of brain activity can be retrieved in many ways, with the most common being Electroencephalography (EEG), Functional Magnetic Resonance Imaging (FMRI), and Positron Emission Tomography [1].
The EEG is an instrument that can capture brain waves as electrical signals based on varying brain activity. The EEG is portable and almost non-invasive compared to the other devices used to retrieve brain signals [2]. Comparisons between such devices show that EEG is the best way to produce signals of the brain activities, and these EEG signals are recorded as electrical waveforms by utilizing special electrodes placed on the human head. These electrodes can measure brain fluctuations as a voltage resulting from ionic current within the brain neurons [3]. EEG signals are usually of small amplitudes and low frequencies, and are influenced by many patient circumstances, such as recording environment, mental state, electrical interference from other organs, health, age, activity, and external stimuli.

The characteristics of EEG signals are generally non-stationary and random which add complexity to the processing of EEG signals. Classification of different EEG waves can explain activity in the brain by interpreting these different waves into different electrical signals. In the classification, signal transformation is required where identification and quantification of EEG signal spectrum are used. EEG signal consists of many wave types, such as alpha waves (8-13 Hz) are arisen with closing of eyes and relaxation conditions, beta waves (14-26 Hz) are captured during conditions of thinking or intending to do activities, theta waves (4-7.5 Hz) occurs during emotional condition, and delta waves (0.5-4 Hz) occurs with sleeping. In most researches, including this work, the range of beta waves are adopted in signal analysis and transformation because they are often arisen with conditions of thinking and intending of doing some activities. Figure 1 shows an example of the EEG signal [4].

The EEG method records human motivations from the nerves of the brain. In the form of electrical signals [5]. Different brain waves (different amplitudes and frequencies) are generated according to human thoughts. Even for a muscle contraction, it will also generate a unique electrical signal [6]. These brain signals are analysed and processed to determine the mental commands that represent certain thoughts. The success of IWs is predicted by verifying two important properties, such as high performance and low cost. For the performance, as in the other intelligent service systems and robots, the main performance evaluation of IWs is based on:

(i) Autonomous navigation capability for good safety, flexibility, mobility, obstacle avoidance, etc.
(ii) Intelligent interface between the users and the IWs.
(iii) Adaptation of IW control technique for the type and the degree of handicap.

Several works have attempted to develop controlled IWs. Utama et. al. [7] used an EEG sensor to control wheelchairs in a design based on blink detection and attention; a LabVIEW-based programming control centre with an Arduino were used as a communication between input and output components. An ultrasonic distance sensor HC05 was used as a wheelchair safety. Arzak et al. [8] utilised a proportional integral derivative (PID) controller, where the input encoder was used as feedback for the PID control at each wheel. Experimentations here showed that the human brain waves can be used to adjust the rate of speed of the wheelchair. Swee et al. [9] further processed EEG signals as control signals to be sent to the microcontroller of the wheelchair, where Bluetooth is used to connect these systems wirelessly. Charles [10] presented a novel method based on the use of a wave sensor to retrieve brain waves, and then these waves are transmitted through Bluetooth to a Level analyzer unit (LAU) which converted these signals using MATLAB platform and send them to robot module as control commands. This system could thus control the movements of the robot according to the brain thoughts with turns controlled by blink muscle contractions.

In this paper, a novel design and implementation of a prototype of an IW is presented in terms of controlling the IW using EEG signals. These signals are processed and interpreted as input to an Arduino Uno Microcontroller. An electronic circuit is designed from the instruments of HC-5 Bluetooth module, Arduino Uno microcontroller and L298N driver for receiving processed EEG signal and controlling (ON-OFF) the direction for two DC motor of wheelchair as will be demonstrated later. The mind wave Neurosky sensor is firstly placed on the brain of the volunteer, and then the sensor and wheelchair are run to pair the Bluetooth modules in them. Four cases were implemented by volunteers; in the first case, the volunteer is thinking and the mind wave Neurosky sensor is sensed the EEG signal which is processed by Think Gear ASIC module (TGAM) board leading to transmit digital values via TXD pin of Bluetooth (represents as master module) linked with TGAM board. In the second case, the volunteer is relaxing, while in the third case, the volunteer is returned to think and in the fourth case, the volunteer is returned to relaxation, the analogue value changes in accordance to the patient case. Examples of different brain signals are illustrated in Figure 1.
2. Proposed EEG based system
A block diagram of the proposed system is illustrated in Figure 2. The proposed system includes three main stages: the first is signal import relating to signal normalization and filtration. The second stage contains three units: feature extraction, signal classification and processing. Third stage, a pulse width modulation (PWM) control signal is produced to drive the DC motors based on thinking mode.

![Figure 2 Block diagram of the proposed system.](image)

**Figure 1** Example of EEG signals for different brain cases [4].
3. DC motors in medical applications

3.1. Wheelchairs based DC motors

The design of control systems for wheelchairs differs by company as well as being dependent on function. The control system of an electric wheelchair has various requirements so as to be comfortable and safe. Some wheelchair specifications are listed below [11]:

1. A wheelchair using DC motors should work at a specific start-up time and must have soft rotation to ensure a smooth movement and to avoid the uneasiness associated with general DC motor. It is important for the start-up time to be fast, less than 5 seconds.
2. In the electric wheelchair, overshoot is not allowed at high speed unlike in general DC motor control systems.
3. Comfortable mode should be taken into account in the process of adjusting speed and it must have certain time to be smooth enough without oscillation.
4. The control system should have a rigid ability of anti-load disturbance.
5. Like the start-up, the braking process time should be fast and smooth, in the range of 2-6 seconds.

3.2. Modelling of a DC motor

Many industrial types of equipment driving a load need a prime mover, there are many types of prime movers, but electric motor represents the most commonly used equipment for this purpose. Electric motors have essential advantages represented by various characteristics; such as speed-torque, speed-current. These characteristics could be adjusted by a control equipment, and such motors also have good starting torque at the start of a load. In terms of practical implementation, using a DC motor to drive a system is a very simple way to achieve phase control. A started separately excited DC motor equivalent circuit and its drive system are shown in Figure 3 [12][13].

![Driving circuit for a DC motor connected with H-Bridge.](image)

### Mathematical Expressions

The mathematical expressions those are indicating the behaviour of the separately excited DC motor segments are shown below:

1. \[ V_a = R_a i_a + e_b \]  
2. \[ T_m = K_t i_a(t) \]  
3. \[ e_b = e_b(t) = K_b \frac{d\omega(t)}{dt} \]

Torque constant (Kt)=Back emf constant(Kb)

where \( V_a \) is armature voltage, \( R_a \) is armature winding resistance, \( i_a \) is armature current, \( e_b \) is back emf voltage, \( T_m \) is torque developed by the motor in N.m.[12]. In the current research, control of the MOSFETs[Q1, Q2, Q3, Q4] is demonstrated as in Table 1. It can be seen that DC motor operation
depends on though status, and these logical control scenarios can be implemented in real-time according to EEG signal levels.

| EEG Signal Status          | Switching Sequences | Mode   |
|----------------------------|---------------------|--------|
| Rest                       | Q1, Q2, Q3 and Q4 are OFF | Break  |
| Mental thinking positive (+ve) | Q1 & Q4 are ON       | Forward |
|                            | Q2 & Q3 are OFF      |        |
| Mental thinking negative (-ve) | Q2 & Q3 are ON       | Backward |
|                            | Q1 & Q4 are OFF      |        |

3.3. Speed control of DC motor using PWM technique

PWM signals are commonly used to control the speed and direction of rotation of DC motors. Any changes in duty cycle will lead to change in the PWM signals, and then the DC motor voltage will be changed, leading to control the speed of the DC motor accordingly. The DC motor speed is directly proportional to the applied voltage. Regulating the switch between the load and the supply ON and OFF at a fast pace is commonly used to control the average value of voltage fed to the load, where the switch is ON for a longer period compared to the OFF period, and higher power will be applied on the load. The duty cycle represents the proportion of ON time to a regular interval or period of time, a high duty cycle corresponds to high power and vice versa, as in the latter most of the time the power is OFF. Figure 4 shows the PWM signal logic, where “on” time is referred to as the “duty cycle” and is stated as a percentage, calculated as:

\[
Duty\ Cycle\ (\%) = \frac{On\ time}{Period} \times 100
\]  

(4)

In Figure 4 a duty cycle of different percentage such as (25%, 50%, and 75%) are thus presented along with average voltages of the PWM signals[14,15].

![Figure 4. speed control of DC motor with duty cycle variations.](image-url)
3.4. Control of DC motor direction

In practical use, such as in a wheelchair, it is both necessary and possible to change rotation direction of the DC motor, and this can be achieved by changing the voltage polarity applied to the winding of the DC motor armature. For this purpose an H-bridge configuration is used, as an efficient and accurate way for controlling the DC motor direction. Figure 5 shows a circuit diagram of the H-bridge configuration for both directions, where in forward direction Q1 and Q4 are ON-stated while Q2 and Q3 are OFF-stated. For the backward direction Q2 and Q3 are in the ON state while Q1 and Q4 are in the OFF state [14,15].

![H-bridge configuration diagram](image)

Figure 5. Implementation results of rotation direction using EEG.

4. Implementation of the proposed IW system

This section considers the experimental work undertaken for this research, based on steps shown in Figure 6. It explains the instruments and tools of the proposed BCI system, where brain wave sensors such as mind flex and mind wave Neurosky sensor are employed in this system. In the first sensor, signal processing for EEG signal using Arduino Microcontroller is implemented with wrong way leading to destroy the sensor. The modelling of the wheelchair controlled by EEG signal of some volunteers is elucidated in this section, with the Arduino IDE is utilized for the wheelchair control.

![Flow chart for experimental work](image)

Figure 6. Flow chart for the experimental work.
4.1. Instruments and tools of the proposed brain computer interface
The specifications of the microcontroller are summarised in Appendix B.

4.2. EEG signal processing using an Arduino Microcontroller
To access the EEG signals from a volunteer using an Arduino Uno Microcontroller and graphing this in real time with MATLAB GUI software prior to processing required opening the cover of the mind flex sensor and soldering wires to the TGAM board pins connected to the forehead sensor and ear clip. The wires were removed from the sensor and linked with analogy and GND pins, respectively. Initially, a wrong connection was made between the wires and TGAM pins, and the soldering process caused damage to some of the electronics in the TGAM board. The EEG signal was thus simply graphed in real time in the MATLAB GUI.

4.3. Design of a Wheelchair Prototype
By employing a robot car chassis kits bought from UrukTec Electronics Company, a small model of a wheelchair was designed. The car package has a plastic board covered with rough brown paper, two DC motor with gears, two wheels, a steering wheel, two electrical switches, wires for DC motors with different screws and plastic connections. The two DC motors were linked to the plastic board using plastic connections and screws and then the wires were soldered to the DC motors.

An electronic circuit was designed based on HC-5 Bluetooth module, the Arduino Uno microcontroller and the L298N driver for receiving the processed EEG signal and controlling (ON-OFF) the direction for two DC motor of the wheelchair. These devices were placed onto the plastic board and then pasted on using silicon glue, being connected with each other via jumper wires typed male – male and male-female. The TXD and RXD pins of the HC-5 Bluetooth module were connected with the appropriate digital pins (10, 11) of the microcontroller, while the two enable pins and four digital input pins of L298N driver were linked with the digital pins (2, 7, 3, 4, 5 & 6) of the Arduino board respectively. The two wires of each DC motor were associated with the two outputs of each H-bridge of the L298N driver.

Two rechargeable batteries were utilized to power Arduino microcontroller and the two DC motors, with the positive electrode of each battery cut from centre so to link the switch in series. Finally, cardboard covers were placed and affixed on the plastic board to cover the electronic circuit and obtain a small wheelchair form. The schematic diagram for the controlling circuit of two DC motors of wheelchair is illustrated in the Figure 7.

![Control Circuit for Two DC Motors of Wheelchair](image-url)

**Figure 7.** Control circuit for the two DC motors of the wheelchair.
4.4. Wheelchair control via brain EEG signal
The setup diagram of the BCI for controlling wheelchair is shown in Figure 8. The direction of the small modelled wheelchair was controlled by EEG signals from volunteers as exemplified in the Figure 9. The mind wave Neurosky sensor is firstly placed on the brain of the volunteer. Then, the sensor and wheelchair are run to pair the Bluetooth modules of them. Four cases are implemented from volunteers.

In the first case, the volunteer actively thought and the mind wave Neurosky sensor sensed the EEG signals which were processed by the TGAM board leading to transmit digital values via TXD pin of the Bluetooth (the master module) linked to the TGAM board. These values were received by the HC-5 Bluetooth module (the slave module) and read serially using the digital pins of the Arduino Uno microcontroller at range of (0-255) digital values. These values were converted to analogue values (0-1023) by enabling the Digital to Analogue Converter (DAC) of the microcontroller with special software. More focused thinking is led to fix the analogue value at a maximum 1023 which leads to send 5V at 110 ms time duration to the two transistors switches of each H-bridge of L298N driver to pass current through the coils of wheelchair's DC motors and move the wheelchair in forward direction with constant speed.

In the second case, the volunteer relaxed, and the analogue value did not reach the 1023 extreme, this leads to transmit 0V to the four transistors switches of each of the L298N driver's H-bridge so that to stop current passing during the coils of wheelchair's DC motors and the moving wheelchair is stopped. In the third case, the volunteer began to think, again so that the analogue value reached the 1023 ultimate value leading the wheelchair to move in a backward direction at steady speed. In the fourth case, the volunteer again relaxed, the analogue values dropped below the 1023 value and the wheelchair stopped.

![Figure 8. Setup diagram for proposed BCI for wheelchair control.](image)

![Figure 9. Controlling a wheelchair via brain EEG signals: volunteers implementing thinking and relaxation cases.](image)
4.5. Arduino IDE software
To pair the HC-5 Bluetooth module of wheelchair with the bluetooth of mind wave Neurosky sensor, at mode software is implemented for HC-5 Bluetooth. The flow chart of controlling (ON-OFF) direction of DC motors in the proposed wheelchair is illustrated in Figure 10, and the algorithm steps are as follows:
Step1: Read voltage from digital pin 10 connected to the TXD pin of the HC-5 Bluetooth at range of (0-255).
Step2: Convert the digital values obtained in step1 to an analogue values by enabling the DAC of the Arduino microcontroller with map comma (0 – 255 0 - 1023).
Step3: Implement timer at 110 ms.
Step4: If the analogue value equal to 1023 then implement timer at 4000 ms. Apply a counter which increases step by step when the condition is attained.
Step5: If the counter is equal to 1, then the motors are rotated in a forward direction via turning on the digital pins connected to the enablers and input pins of the L298N driver's H-bridges (pin2=130 analogue value, pin3= 0 logic state, pin4= 1 logic state, pin5= 0 logic state, pin6= 1 logic state and pin7=130 analogue value).
Step6: If the counter is equal to 2 then the motors are stopped by turning off the digital pins connected to the enablers and input pins for the H-bridges of the L298N driver. (pin2=0 analogue value, pin3= 0 logic state, pin4= 0 logic state, Pin5= 0 logic state, pin6= 0 logic state and pin7=0 analogue value).
Step7: If the counter is equal to 3 then the motors are spun in backward direction via turning on the digital pins connected to the enablers and inputs pins of L298N driver's H-bridges (pin2=130 analogue value, pin3= 1 logic state, pin4= 0 logic state, Pin5= 1 logic state, pin6= 0 logic state and pin7=130 analogue value).
Step8: If the counter is equal to 4 then the motors are stopped by turning off the digital pins connected to the enablers and inputs pins for the H-bridges of the L298N driver. (pin2=0 analogue value, pin3= 0 logic state, pin4= 0 logic state, Pin5= 0 logic state, pin6= 0 logic state and pin7=0 analogue value).
Step 9: The counter is reset equal to 0.
Step10: Implement timer at 3000 ms.

Figure 10. Flow chart for controlling DC motor rotation in the proposed wheel chair.
5. Verification of the proposed controller based on real-time EEG signals

5.1. Results of DC driver voltage for the wheelchair prototype
As evident in Figures from 11 to 13, the voltage of DC driver for the wheelchair varied in the four modes according to the time interval of thinking applied by the three volunteers. The process of controlling is dependent on the ability of the volunteer to focus on thinking about moving the wheelchair until the maximum value is reached to achieve the required voltage (5V) for control. There are thus differences in timings between volunteers. Tables (2) to (4) depict the controlling cases for the wheelchair for each volunteer showing these with different time durations.

![Figure 11. DC driver voltage for wheelchair controlled by the first volunteer as a function of time duration of volunteer’s thinking.](image1)

![Figure 12. DC driver voltage for wheelchair controlled by the second volunteer as a function of time duration of volunteer's thinking.](image2)
Figure 13. DC driver voltage for wheelchair controlled by the third volunteer as a function of time duration of volunteer's thinking.

Table 2. Representation of each controlling case for the first volunteer.

| Time duration of thinking | DC driver voltage (V) | State   |
|---------------------------|-----------------------|---------|
| 0  to 11                  | 0                     | OFF     |
| 12 to 13                  | 5                     | Forward |
| 14 to 29                  | 0                     | OFF     |
| 30 to 33                  | -5                    | Backward|
| 34 to 45                  | 0                     | OFF     |

Table 3. Representation of each controlling case for the second volunteer.

| Time duration of thinking | DC driver voltage (V) | State   |
|---------------------------|-----------------------|---------|
| 0  to 3                   | 0                     | OFF     |
| 4  to 7                   | 5                     | Forward |
| 8  to 11                  | 0                     | OFF     |
| 12 to 21                  | -5                    | Backward|
| 22 to 45                  | 0                     | OFF     |
Table 4. Representation of each controlling case for the third volunteer.

| Time duration of thinking | DC driver voltage (V) | State |
|---------------------------|-----------------------|-------|
| 0 to 11                   | 0                     | OFF   |
| 12 to 21                  | 5                     | Forward |
| 22 to 24                  | 0                     | OFF   |
| 25 to 30                  | -5                    | Backward |
| 31 to 45                  | 0                     | OFF   |

5.2. Cost of the proposed IW

The life cycle cost (LCC) for an IW can be estimated using Eq.(4) for five years operation[22]:

\[ LCC = C + M + R + F \] (4)

where \( C \) is the initial cost of an IW; \( M \) is a factor related with maintenance fee; \( R \) is the hardware replacement cost; \( F \) is the electricity cost which is calculated as the following steps.

Step 1: Energy estimation per day

\[ E = V \times I \times hrs \]
\[ E = 12 \times 60 \times 8 \]
\[ E = 5.76 \text{ KWh} \]

Step 2: Cost of 5.76 KWh/day is estimated [22]; $0.634/day.

Step 3: Total electricity cost per 5 years is

\[ F = 0.634 \times \$ \frac{\text{day}}{\text{day}} \times 360 \text{ days} \times 5 \text{ years} = \$1,142. \]

Step 4: \( R \) is calculated as: every 6 months we change a 12V battery, \( R = 9 \times 50 = 450 \)

Therefore, \( K = M + R + F = 0 + 450 + 1142 = \$1592 \); this amount will add to estimate LCC for both the proposed and the manufactured systems, which their initial costs are listed in tables 5 and 6.

Table 5. The initial cost of the proposed IW.

| Item                  | Specifications                                                                 | Cost ($) | Quantity | Total price ($) |
|-----------------------|-------------------------------------------------------------------------------|----------|----------|-----------------|
| EEG sensor            | MindWave EEG Headset BLE 4.0                                                 | 200      | 1        | 200             |
| Wheelchair            | McKesson Heavy-Duty Wheelchair with Swing Away Footrests - 24-Inch Seat Width - 1 Each / Each – 24334201 | 200      | 1        | 200             |
| DC Motors             | 24VDC, 240W, 10A                                                             | 300      | 2        | 600             |
| Lithium battery for wheelchair | High quality 24V 20Ah                                                           | 65       | 1        | 65              |
| Arduino               | Uno microcontroller and HC-5 Bluetooth module                                 | 20       | 1        | 20              |

Overall initial cost (\( C \)) for the proposed IW based EEG 1082

\[ LCC \text{ for the proposed IW based EEG} = C + K = 1082 + 1592 = \$2674 \]
Table 6. Initial cost of manufactured passive wheelchair.

| Item                                                                 | Specifications                                      | Cost ($) | Quantity | Total price ($) |
|----------------------------------------------------------------------|----------------------------------------------------|----------|----------|-----------------|
| Manufactured IW based automatic controller                           | Electric Wheelchair Elderly Disabled Car            | 2365     | 1        | 2365            |
|                                                                      | Elderly Intelligent Automatic Portable Scooter     |          |          |                 |
|                                                                      | Multifunctional Folding[23]                        |          |          |                 |
| Overall initial cost (C)for the manufactured system                 |                                                    |          |          | 2365            |

$LCC_{\text{for the manufactured IW based automatic controller}} = C + K = 2365 + 1592 = $3957$

It can be seen that the proposed IW based on EEG is cheaper than the passive manufactured wheelchair and the profit is approximately $1283.

6. Conclusions

This work presents the development, implementation and testing of a brain-computer interface system, to enable speed control of an IW. For many disabled people, electroencephalogram (EEG) signals are used to serve as an interface between the human brain and machines or devices. EEG signals vary due to human mental thinking, which can thus be manipulated to drive a wheelchair in real-time without any muscle efforts. In this paper, an EEG-based brain-controlled DC motor was developed using a Brain Computer Interface (BCI) that included an EEG sensor headset to measure the brain signal, with extracted EEG signals acting as reference signals transmitted to the Microcontroller via a Bluetooth medium. The wheelchair designed includes an Arduino system that drives two DC motors to accomplish the translation of reference EEG signals. The low cost of the proposed system could permit the disabled people to control their wheelchairs independently, improving their quality of life.

7. References

[1] WebMD, 2014, Positron Emission Tomography (PET), [Online], Available: http://www.webmd.com/cancer/lymphoma/positron-emission-tomography.

[2] T. F. Collura, 1997, The Measurement, Interpretation, and Use of EEG Frequency Bands. EEG Frequency Bands.

[3] E. Niedermeyer & B. F L. Silva, 2005, Basic Principles, Clinical Applications and Related Fields, Electroencephalography.

[4] J. G. Webster. 1999, Medical Instrumentation: Application and Design/Wiley, Singapore.

[5] K. H. Solanki, H. Pujara, 2015, Brainwave Controlled Robot, International Research Journal of Engineering and Technology (IRJET), 2, 609 - 612.

[6] K. Yendrapalli , S. S. N. P. K. Tammana, 2014, The Brain Signal Detection for Controlling the Robot, International Journal of Scientific Engineering and Technology, 3, 1280-1283.

[7] J Utama, M D Saputra, 2018, Design of electric wheelchair controller based on brainwaves spectrum EEG sensor, IOP Conf. Series: Materials Science and Engineering 407.

[8] M.I. Arzak, U. Sunarya, S. Hadiyoso, 2016, Design and Implementation of Wheelchair Controller Based Electroencephalogram Signal using Microcontroller, International Journal of Electrical and Computer Engineering (IJECE),Vol. 6, No. 6, pp. 2878~2886.

[9] Sim Kok Swee, Lim Zheng You,K ho Teck Kiang, 2016, Brainwave Controlled Electrical Wheelchair, MATEC Web of Conferences.
[10] Pranob Kumar Charles, Murali Krishna, 2018, Praneeth Kumar GV and Lakshmi Prasad , “EEG - Controlled Wheelchair Movement: Using Wireless Network, J Biosensors & Bioelectronics.

[11] Ahmad G. W. Rahman, Renaldo H. Putra , Didik S. Purnomo and Endah S. Ningrum, 2017, Electric Standing Wheelchair Controller to Provide User Safety and Comfortness”, International Medical Device and Technology Conference.

[12] p. karpagavalli and a. ebenezer jeyakumar, 2015, pid controller based full bridge dc-dc converter for closed loop dc motor with unipolar voltage switching, u.p.b. sci. bull., series c, vol. 77, iss. 1.

[13] Nashwan Saleh Sultan, Rakan Khalil Antar and Bashar Abbas Fadheel,2018, A Comparative Control Study of a Separately Excited DC Motor Using Intelligent Controllers, Journal of Engineering and Applied Sciences 13 (22): 9799-9805.

[14] Vibhor Gupta, 2010, Working and Analysis of the H – Bridge Motor Driver Circuit Designed for Wheeled Mobile Robots, IEEE, pp 441-444.

[15] Hsin-Chuan Chen, 2013, An H-Bridge Driver Using Gate Bias for DC Motor Control”, 17th International Symposium on Consumer Electronics (ISCE), IEEE, pp 265-266.

[16] Aliexpress, 2019, Bluetooth EEG sensor / EEG acquisition module of /TGAM kernel mind control development, www.aliexpress.com.

[17] www.mindflezgames.com, "mind flex game", Mattel, Inc.,2009.

[18] Shayela Nausheen Aziz, Naveen Kumar Dewangan , Vinni Sharma, Aug. 2018, Analysis of Electroencephalogram (EEG) signals, Dept of Electronics Engineering, BIT, Durg, C.G., India.

[19] Riitta Hari & Aina Puce, 2017, MEG-EEG Primer, Oxford university.

[20] NeuroSky, 2011, "MindWave User Guide", NeuroSky, Inc.

[21] Guangzhou Tiger Head Battery Group, "ALKALINE BATTERY", Focus Technology Co., Ltd, 1998-2019.

[22] Ali Jafer Mahdi, Bashar Abbas Fadheel, Dec. 2018, A Modified Algorithm for Economic Evaluation between Diesel-Generator and PV Solar System”, 2nd International Conference for Engineering, Technology and Science of Al-Kitab University, pp83-87.

[23] https://www.amazon.com/Electric-Wheelchair-Intelligent-Automatic-Multifunctional/dp/B07H34MZ25.