Bulletin of Electrical Engineering and Informatics
Vol. 10, No. 6, December 2021, pp. 3032~3041
ISSN: 2302-9285, DOI: 10.11591/eei.v10i6.3200

Wheelchair controlled by human brainwave using brain-computer interface system for paralyzed patient

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Article Info

Article history:

Received Dec 2, 2020
Revised Mar 30, 2021
Accepted Oct 17, 2021

Keywords:

Attention level
Brain-computer interface
Electroencephalography
Eyebrow movement
Threshold value

ABSTRACT

Integrated wheelchair controlled by human brainwave using a brain-computer interface (BCI) system was designed to help disabled people. The invention aims to improve the development of integrated wheelchair using a BCI system, depending on the ability individual brain attention level. An electroencephalography (EEG) device called mindwave mobile plus (MW+) has been employed to obtain the attention value for wheelchair movement, eye blink to change the mode of the wheelchair to move forward (F), to the right (R), backward (B) and to the left (L). Stop mode (S) is selected when doing eyebrow movement as the signal quality value of 26 or 51 is produced. The development of the wheelchair controlled by human brainwave using a BCI system for helping a paralyzed patient shows the efficiency of the brainwave integrated wheelchair and improved using human attention value, eye blink detection and eyebrow movement. Also, analysis of the human attention value in different gender and age category also have been done to improve the accuracy of the brainwave integrated wheelchair. The threshold value for male children is 60, male teenager (70), male adult (40) while for female children is 50, female teenager (50) and female adult (30).

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1. INTRODUCTION

Problem statement; there are many technologies that have been developed to help the disabled person but it is still limited, particularly for the paralyzed patient like quadriplegic or sometimes known as tetraplegic who cannot move their both legs and arms due to severe motor impairments such as amyotrophic lateral sclerosis (ALS). It is specifically for the paralyzed patient, that has no significant damage to their sensory nerve cells. Thus, sensory neurons still can be used to transmit the brain signal to control external devices. Human brainwave constantly emits the electrical signal as a way of sending information to all parts of our body. The procedure of sending signal never ceased even for the paralyzed and the physically handicapped.

Nowadays, there are many types of research about brain-computer interface (BCI) that have been considered to help the disabled people for example, mind-controlled wheelchair. Yet, when brainwave is used to control the integrated wheelchair, it requires a longer time for the wheelchair to move due to unstable signals in time response due to different types of human brainwaves being produced. Besides that, the accuracy of the wheelchair from the previous works need to be improved as the wheelchair move continuously when using only human attention value as an input. Therefore, the efficiency of the brainwave controlled wheelchair can be improved using human brainwave in terms of attention value, blink detection and eyebrow movement. Besides that, the reduction in cost also can be done when using modification of the manual wheelchair into the electric wheelchair and using the cheapest brainwave sensor which consist only single electrode. Thus, it is possible to help the physically disabled person to move. Analysis on human attention for different gender and age are crucial in ensuring the efficiency of the integrated wheelchair could be optimized and improved.

Literature review; BCI system is a system that can bypass conventional channels of communication (ie., muscles and thoughts) to provide direct communication and command between the human mind and physical devices by translating different patterns of brain activity into output commands in actual time [1]-[3]. This can be done by positioning the electrode around the head to notice the signal or more precisely producing the brainwaves and then transporting the information to the computer for analysis [4].

Electroencephalography (EEG) is the process of recording electrical impulses occurring at the scalp. These impulses occur due to the ionic flow of current within neurons [5]. This is done by reading measurements detected by electrodes placed over the scalp [6]. The use of EEG is usually associated with diagnosing certain neurological abnormalities such as dementia and epilepsy [7]. EEG comprises a set of signals which may be classified according to their frequency [8]. Several types of waves can be classified as alpha (∝), delta (δ), theta (θ), beta (β) and gamma (γ) based on their frequency range [9]. It is possible to configure the mental states and condition of the individual by deciding the form of brainwave that is being generated [10].

An EEG device called mindwave mobile plus (MW+) (refer Figure 1) has been used in this research to acquire data of brainwave signals in term of attention level, blink detection and eyebrow movement to control the integrated wheelchair's movement by human brainwave using the BCI system for helping a paralyzed patient. The analog human brainwave has been converted to produce the digital value of attention level (range 0-100), eye blink detection (0-255) and signal quality value (0-200) [11]. The attention level has been converted using an EEG technique while eye blink detection has been acquired using Electromyography (EMG) technique [12]. Mindwave mobile has been compared with a wet electrode EEG system named Biopac, which is used in medical and research applications. The results show that differences between measurements are very small and acceptable [13], [14].

Figure 1. Mindwave mobile [15], [16]

eSense attention meter shows the concentration and focus of mindwave mobile users. Disturbances, drifting thoughts, less focus or anxiety can lower the level of the person's attention [17]. The attention level was categorized into five levels, which were "poor attention" (1-19), "less attention" (20-39), "neutral" (40-59), "good attention" (60-79) and "great attention" (80-100). People with "great attention" level which range between 80 and 100 have very high concentration level at that time [18].

MW+ uses the EMG technique which will detect the muscle contractions that occurs while blinking the eye and this contraction will generate a unique signal [19]. A blink detection algorithm signals blink from a user. A higher number indicates a "stronger" blink, while a smaller number indicates a "lighter" or "weaker" blink. Eye blinks are identical to a regular binary on/off binary system and are thus useful for controls needing definitive responses. For example, one blink implies no in communication applications, two implies yes-giving individuals with special needs a simple way of communicating [20].

The signal quality values between 0 to 200 and 0 are the best while 200 is the most defective. As an added safety precaution in this project, a stop command will be committed to the integrated wheelchair when the signal quality value is not respectable to prevent any unwanted movement [21]. It can be performed by lifting up the eyebrow to get non-zero value of signal quality when the signal quality is equal to 26 or 51 is produced. Once the signal quality value turns into good which is zero value, the microcontroller begins listening for any incoming force blink data from the MW+ [22].

These values were used to control the brainwave integrated wheelchair in terms of movement (attention level), mode (eye blink) and stop for emergency alert (eyebrow movement) [23]. Based on the analysis, the threshold value for the human attention value was set differently according to the gender and age category of the user, the mode of the wheelchair changed in the sequence of forward (F), to the right (R), backward (B) and to the left (L) when the eye blink is detected. Eyebrow movement has been used to execute the stop mode as an added precaution when using human attention level to move the wheelchair.

Limitation of previous projects; Table 1 shows some limitations of the former works in developing brainwave integrated wheelchair or analyzing the human brainwave signals using BCI technique. Based on the limitations occur in the previous works, there are some solutions that has been done in this research to overcome the disadvantage which can be shown as follows;

a. The project uses a mind wave headset instead of traditional EEG to acquire brain signals, thereby reducing the set-up time. The upgrade edition of the neurosky mindwave mobile headset was used which is mindwave mobile plus which does not need to take pairing mode and can link to the bluetooth low energy (BLE) bluetooth. Besides that, portable EEG device was used in this project. The advantage of using a portable EEG brainwave headset is that it uses a dry active sensor technology to read brain electric activity.
b. Advantageously, the invention presents a technical feature such that these EEG artifacts characterized as facial muscle movements such as eye blinks and eyebrow movements are being utilized to generate an instruction defining the movement of the wheelchair and is further configured to execute a “STOP” instruction upon exceeding a predetermined threshold EEG signal value.
c. Analysis of the human attention value based on the age category and gender differences has been done as these factors can affect the human attention level produced by the humans. The threshold value of the brainwave integrated wheelchair has been set according to the gender and age category of the user.
d. Non-invasive technique of BCI was used which does not need to implant electrode inside the skull (non-dangerous).
e. The reduction in cost by making the design as a conversion kit for a regular wheelchair; the project doesn’t reinvent the wheel; it instead builds on top of an existing framework and brings together the best of things. The mechanical modifications are narrowed down to a point where it can be reproduced easily and invested on other manual wheelchairs. Besides that, the cheapest brainwave sensor consists of single electrode is applied.
f. MDDS30A motor driver was used to control the speed and direction of wheelchair which is easy to use and has simple algorithm.
g. The eyebrow movement of the user is used for stop emergency alert when applying the attention value of the user for moving the wheelchair.
h. LED and LCD were added to enable the user to recognize the instruction mode and the attention value of the user in real time.

Table 1. Previous work and its limitations

	Limitations of Previous Projects	References
1. Brainwave analysis	Using traditional EEG which require a long time to acquire the brain signals. Having complex sensors and processing.	[24]-[26]
2. Bluetooth connection	It sometimes takes a long time to connect which is about 2-3 minutes. Need to take pairing mode when using previous Mindwave Mobile.	[23], [27], [28]
3. Display	Does not have a good display to know the mode of the wheelchair and the brainwave signals need to be analyzed in analog form.	[29], [30], [31]
4. Wheelchair movement	Not being stable when using human brainwave as an input for the wheelchair. The wheelchair continue to move continuously when the human attention value is higher and difficult to control.	[3], [32]
5. Emergency alert	Doesn’t have any safety and emergency alert which is very risky and not compatible for the disabled people	[2], [11]
6. Brainwave analysis on the real subject	Focus only on hardware and not being implemented into the real subject.	[3], [33]

2. RESEARCH METHOD

2.1. Block diagram of the brainwave detection system

Figure 2 shows the block diagram of the brainwave detection system for wheelchair. A system for controlling the movement of the wheelchair comprising a brainwave sensor which is MW+ was attached onto a user’s skin for detecting their brainwaves and facial movement using EEG and EMG technique. A brain signal which has been generated from detected brainwaves will be processed and converted into digital value and classified according to attention value (0-100), signal quality value (0-200) and blink strength value (0-255) and transmitted to the Arduino microcontroller via HC-05 bluetooth module.

There were two Arduino that has been used in this project, as indicated in Figure 2. First Arduino, which is Arduino MEGA (Arduino 1) was for attention value and signal quality value while the second Arduino UNO (Arduino 2) was for the eye blink detection. These values act as an input and Arduino send instructions to the power window motor for controlling the wheelchair via MDDS30A motor driver. At the same time, LED and LCD was used to display the attention value and the command mode of the wheelchair. In Arduino 2, the eye blink detection occurs when the blink strength value is higher than 110 and below 250 which change the mode of the wheelchair in sequence (forward, right, backward, left). This output will sent to the Arduino 1 for controlling the direction of the wheelchair. The threshold value of the wheelchair movement was set according to the gender and age category of the user. Arduino 1 will send the instructions to the power window motor based on the input attention value, signal quality and eye blink detection. The wheelchair will move in selected mode when the attention value of the user is higher than the threshold value and signal quality value is good which is zero value. To stop the wheelchair after being moved because of the higher attention level, eyebrow movement is used as the signal quality of certain value is produced.

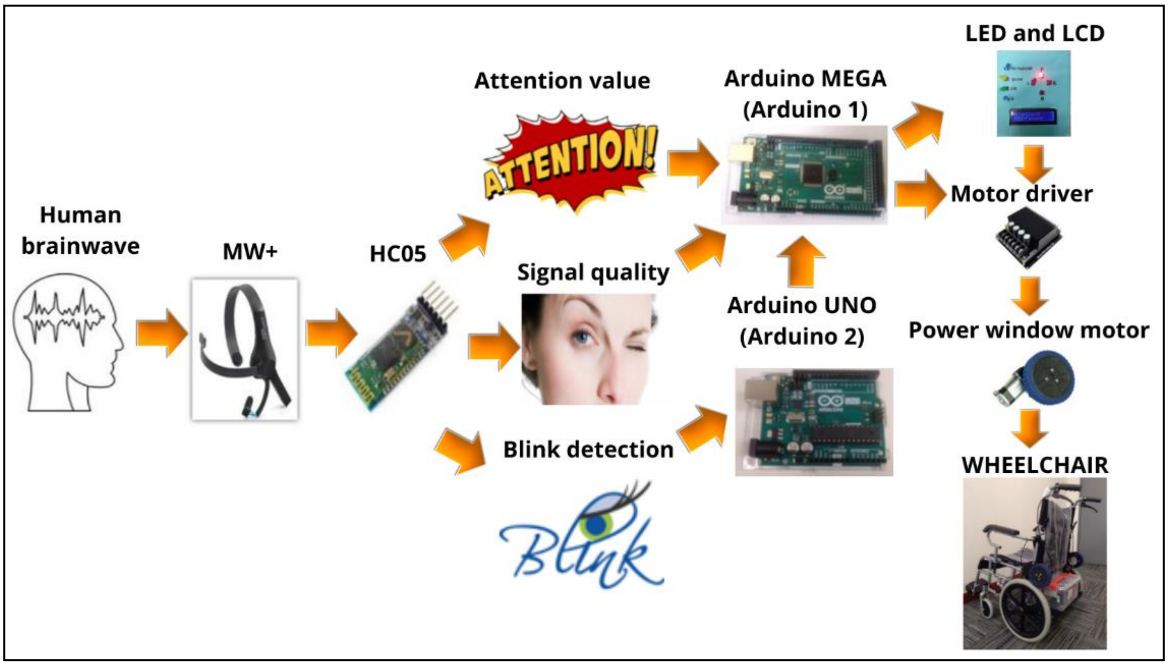


Figure 2. Block diagram of the brainwave detection system

2.2. Analysis method

Figure 3 shows the output results in the serial monitor of Arduino. An Arduino IDE software was used to obtain brainwave signals of the human based on the attention, signal quality value and blink detection in digital form. The range of the attention value is from 0 to 100 while the signal quality value ranging between 0 to 200.

Statistical analysis was carried out in order to study the effect of gender (male, female) and age category (children, teenager, adult) on the attention value produced by the human for improving the development of the brainwave integrated wheelchair [34]. Thirty (30) subjects were selected for the analysis of the human’s attention value. There were 10 children, 10 teenagers and 10 adults. Statistical analysis was performed using SPSS version.

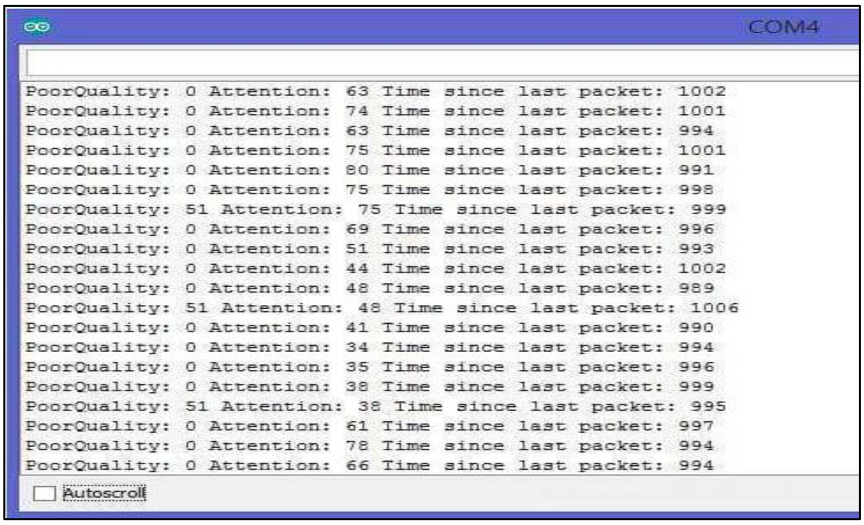


Figure 3. Attention level and signal quality of the user in serial monitor

3. RESULTS AND ANALYSIS

3.1. Wheelchair development

The complete wheelchair has been presented in Figure 4. Referable to the differential drive mechanism, each wheel was attached to its own power window motor. Power window motor was selected as motor and MDDS30A as a motor driver for this wheelchair. The AAA battery was used to supply power to the MW+ while the 9 V battery was used to supply power to both of the Arduino and the SLA battery to the power window motor. It is really important to have an adequate supply to make sure the wheelchair can be functioned properly when being used by the user. Therefore, a rechargeable AAA battery and rechargeable SLA battery were used to avoid the problems. The Arduino can be powered through the external power jack provided on the board. The mode of the wheelchair can be identified by using LED as an indicator and the sequence of the mode is forward (F), right (R), backward (B) and left (L). The stop (S) mode is taken when the eyebrow movement is occurring as it is being applied for an emergency warning signal when using the human brainwave signals as a control. The Arduino also being connected to the liquid crystal display (LCD) for displaying the value of the user's attention and the mode of the wheelchair in real time.

Figure 4. Brainwave integrated wheelchair

3.2. Wheelchair testing

3.2.1. Time taken for signal quality from the brainwave sensor

To ascertain the wheelchair, 10 teenagers (5 males and 5 females) which are students from Universiti Tun Hussein Onn Malaysia were selected to test the movement of the wheelchair when the attention value of the subject is higher than the threshold value, change the mode when user's blink the eye and stop when make an eyebrow movement. Time of delay for the wheelchair to move assigned by the user has been recorded. Table 2 shows the time of delay for the wheelchair movement controlled by human brainwave signals for every aspect of the movement. The result shows that the longest time for the average of time is during the right movement while the shortest average time of delay from the serial monitor of Arduino to the wheelchair is when doing the backward movement.

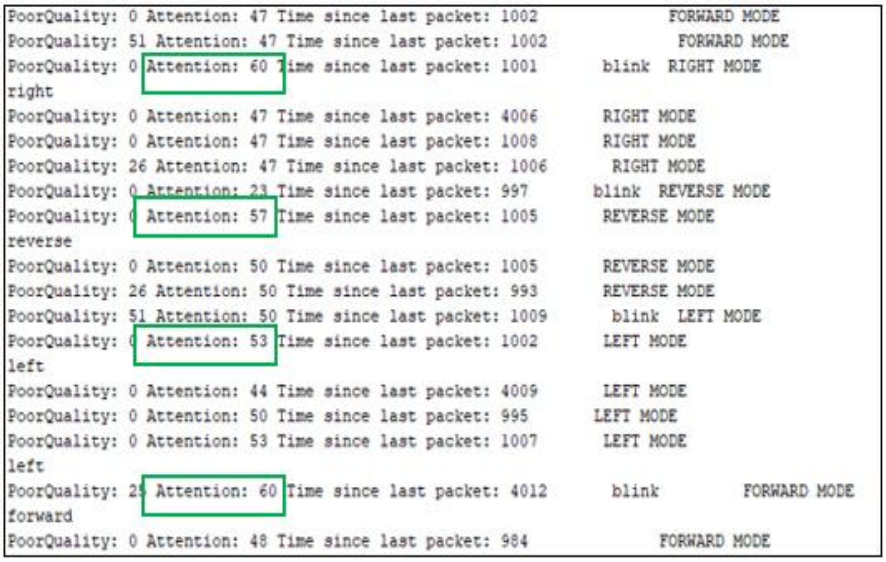
Table 2. Delay time of the wheelchair movement

Subject	Time of delay from serial monitor to the wheelchair (ms)				
	Forward (F)	Right (R)	Left (L)	Backward (B)	Stop (S)
1	1018	1022	999	1005	991
2	990	1001	1010	997	1002
3	1004	4006	4010	994	1002
4	1002	4014	1002	1004	1002
5	1000	1025	1007	988	1009
6	1004	3988	1014	995	1001
7	1009	1000	1000	1001	1007
8	998	998	997	998	996
9	1003	1001	2991	1018	1004
10	1020	4005	990	1002	1011
Average	1005	2206	1502	1000	1003

3.3. Brainwave analysis of the human

3.3.1. Analysis of brainwave signals based on the attention value of the user

Figure 5 shows the value of attention produced by the user in the real time. For this experiment, the threshold value was set to 50. This threshold value is not fixed and can be changed differently depending on the ability of the user. Threshold value of 50 has been used as this value is the minimum hardness that being produced by the user. Therefore, when the attention value raises the threshold value, the wheelchair will move to the selected mode assigned by the user. For example, in Figure 5, the serial monitor will print “right” as the attention value is 60 which is higher than 50 indicates that the wheelchair will move to the right at that time.



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PoorQuality: 0 Attention: 47 Time since last packet: 1002        FORWARD MODE
PoorQuality: 51 Attention: 47 Time since last packet: 1002       FORWARD MODE
PoorQuality: 0 Attention: 60 Time since last packet: 1001    blink  RIGHT MODE
right
PoorQuality: 0 Attention: 47 Time since last packet: 4006    RIGHT MODE
PoorQuality: 0 Attention: 47 Time since last packet: 1008    RIGHT MODE
PoorQuality: 26 Attention: 47 Time since last packet: 1006   RIGHT MODE
PoorQuality: 0 Attention: 23 Time since last packet: 997     blink  REVERSE MODE
PoorQuality: 0 Attention: 57 Time since last packet: 1005    REVERSE MODE
reverse
PoorQuality: 0 Attention: 50 Time since last packet: 1005    REVERSE MODE
PoorQuality: 26 Attention: 50 Time since last packet: 993    REVERSE MODE
PoorQuality: 51 Attention: 50 Time since last packet: 1009   blink  LEFT MODE
PoorQuality: 0 Attention: 53 Time since last packet: 1002    LEFT MODE
left
PoorQuality: 0 Attention: 44 Time since last packet: 4009    LEFT MODE
PoorQuality: 0 Attention: 50 Time since last packet: 995     LEFT MODE
PoorQuality: 0 Attention: 53 Time since last packet: 1007    LEFT MODE
left
PoorQuality: 25 Attention: 60 Time since last packet: 4012   blink     FORWARD MODE
forward
PoorQuality: 0 Attention: 48 Time since last packet: 984         FORWARD MODE
```

Figure 5. Output of attention value on the serial monitor

3.3.2. Analysis of brainwave signals based on the user’s eye blink detection

Figure 6 shows the output of mode changing of the wheelchair in the serial monitor that happened when the user blinks his or her eye. The sequence of the mode is forward, right, backward and left and it will repeat again.

3.3.3. Analysis of brainwave signals based on the eyebrow movement of the user

The stop mode of the wheelchair can be executed when the user makes the eyebrow movement as 26 or 51 signal quality has been produced which can be seen in Figure 7. When the wheelchair moves because of the attention level produced by humans, this stop command can be used to stop the wheelchair.

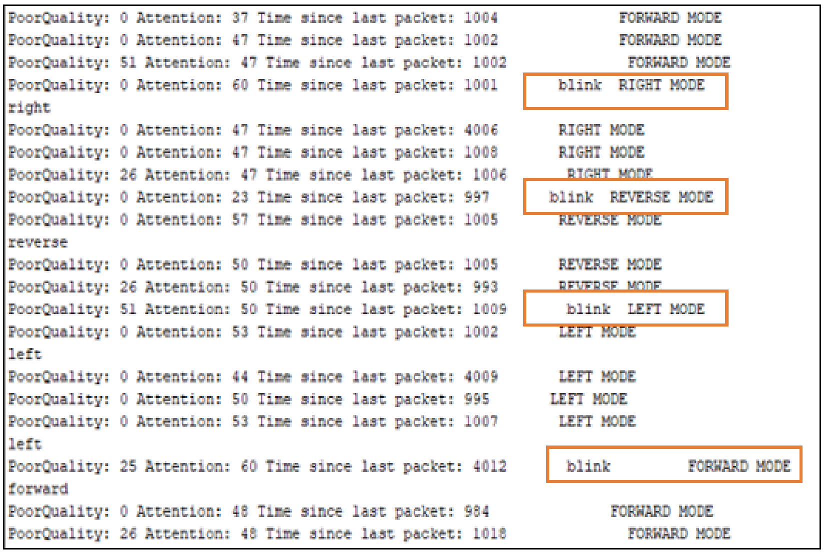

Figure 6. Output for the mode changing in the serial monitor

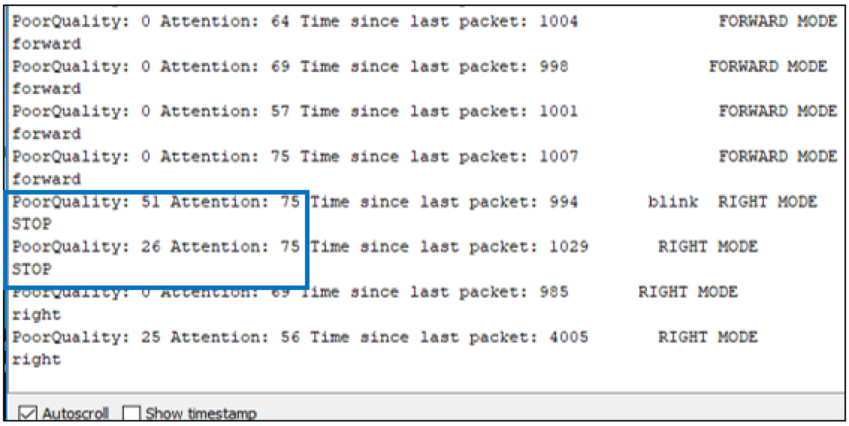

Figure 7. Output for the signal quality from the serial monitor

3.4. Analysis of human's attention value in gender and age category

3.4.1. Effect of gender on the attention value of the human

An independent-samples t-test was conducted to compare attention value for every aspect of movement between males and females with the level significance, α=0.05. The assumption of normality and homogeneity of variances has been made before conducting the independent sample t test. The data were analyzed by using SPSS. Since the sample size is small, n=15, Shapiro Wilk test is used to test the normality of the sample. If the p value is higher than level of significance, the distribution of the sample is normal [35]. Attention level for each level of gender were normally distributed, as assessed by Shapiro-Wilk test (p >. 05).

Results in Table 3 shows the Levene's and t test for independent sample t test. Levene's test checks the null hypothesis that the variances of the two groups are equal. If the significant value for Levene's test is higher than significant level of 0.05 (p > .05), the assumption of equal variance is met and t value at the top row of the output table is chosen. In table for forward movement for example, its p value is 0.034 which is less than significant level, so the assumption of equal variances is violated so the bottom row of the output table is chosen. Based on the results in SPSS, homogeneity of variance as accessed by the Levene's test is not met only for forward movement. Therefore, the data results associated with the "Equal variances not assumed" is used for the forward movement.

Null hypothesis for the independent sample t test is that there is no difference in mean attention value between male and female while the alternative hypothesis is that there is a difference in mean attention value between male and female. The null hypothesis is rejected if the p value is less than the level of significance which alpha 0.05 is used in this data analysis. The value of the t statistic for the forward movement is 2.142 and the p-value is displayed 0.043. This means that there is a very small probability of this results occurring by chance under the null hypothesis of no difference between the two groups.

Table 3. Comparison between male and female participants on attention

Dependent variable	Levene's test for equality of variances			t-test for equality of means			
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference
Forward (F)	Equal variances assumed	4.956	0.034	2.142	28	0.041	12.67
	Equal variances not assumed			2.142	22.734	0.043*	
Right (R)	Equal variances assumed	1.152	0.292	0.687	28	0.498	4.40
	Equal variances not assumed			0.687	25.422	0.498	
Left (L)	Equal variances assumed	2.370	0.135	-0.556	28	0.583	-3.00
	Equal variances not assumed			-0.556	26.523	0.583	
Backward (B)	Equal variances assumed	0.634	0.432	-0.066	28	0.947	-0.40
	Equal variances not assumed			-0.066	27.787	0.947	
Stop (S)	Equal variances assumed	0.063	0.804	0.358	28	0.723	2.20
	Equal variances not assumed			0.358	27.947	0.723	

Note: *significant at p < .05

The null hypothesis is formally rejected with 95% confidence since p < .05. In this case, the attention value of male and female is different when doing the forward movement in the mean attention value of male, approximately 12.67 higher than female [forward score: male=88.47, female=75.80]. However, there were no significant differences between male and female participants for another four aspects of the movement.

3.4.2. Effect of age category on the attention value of the human

The data in Table 4 reveal differences between the three categories of age across the five types of thought movement for the attention value. Shapiro-Wilk test was used to test the assumption of normality and Levene's test for the assumption of homogeneity of variance. Based on the result in SPSS, the data were normally distributed as the p of the Shapiro-Wilk test is higher than alpha level. For the homogeneity of variance, result shows that the F value of Levene's test for the forward, left and backward mode are 0.71, 0.10 and 2.07 with a sig. (p) value of .50, .91 and .15 concluded that the assumption of homogeneity of variance is met. Whereas, for the other two movements, the sig. value is less than the alpha level concludes that, significant difference is shown between the group's variance. Using an alpha level of 0.05, one-way ANOVA test was used to determine if there is a significant difference in the attention value of participant among age categories which are children, teenager and adult. The result shows that there was no significant difference between age categories on the attention value for every mode.

Table 4. Effect of age category on attention value

Dependent variable	Homogeneity of variance		ANOVA	
	Levene statistic	Sig.	F	Sig.
Forward (F)	0.71	0.50	0.94	0.40
Right (R)	5.84	0.01	0.38	0.69
Left (L)	0.10	0.91	0.80	0.46
Backward (B)	2.07	0.15	0.10	0.91
Stop (S)	3.95	0.03	0.66	0.53

3.4.3. Threshold value for brainwave integrated wheelchair

Based on the results on the analysis of human attention value in different type of gender and age category, the threshold value to move the brainwave integrated wheelchair can be set differently according to the gender and age specification of the user (refer Table 5). The average threshold value of attention level at all movements is stop mode for each gender and age category. After the user changed the mode of the wheelchair using eye blink detection, the integrated wheelchair will move when the signal quality is good which is 0 value and user's attention level is higher than the threshold value. Stop mode can be done when the user lifts up the eyebrow as the signal quality of 26 or 51 is produced which also reducing the human attention value.

Table 5. Threshold value for brainwave integrated wheelchair

	Male	Female
Children	60	50
Teenager	70	50
Adult	40	30

4. CONCLUSION

In conclusion, wheelchair controlled by human brainwave using a BCI system for helping a paralyzed patient has been developed. In this research, the efficiency of the brainwave integrated wheelchair is improved using human attention value, eye blink detection and eyebrow movement for controlling the wheelchair. Analysis on the human attention value in different gender and age category also has been done to improve the accuracy of the brainwave integrated wheelchair. Based on the findings obtained through the experiment carried out revealed that the gender and age categories could affect the attention level produced by humans. Male is easier to focus compared to the female for every aspect of the movement except for the left and backward movement. The teenager has the highest attention value when making the right and backward movement. While for the forward and stop mode, children's category has the highest attention value and the adult has the lowest attention value of all aspects of the movement.

Since the attention value for every aspect of the movement varies according to age and sex differences, the threshold value of the integrated wheelchair movement controlled by MW+ is set differently based on the gender and age categories of the user. The threshold value for male children is 60, male teenager (70), male adult (40) while for the female children is 50, female teenager (50) and female adult (30). The mode of the wheelchair is changed in sequence of forward (F), to the right (R), backward (B) and to the left (L) when the blink strength value is above 110 and below 250 is detected. As an added safety precaution when using human attention level to move the wheelchair, eyebrow movement is used to execute the stop mode as the signal quality value of 26 or 51 is produced.

This research will open up a whole new possibility for impaired people, they may be able to control a wheelchair using only the power of the mind. With proper control this product could greatly benefit to those with limited to, various disabilities, in conditions of a multifunctional companion robot, or even as a control for driving or for any locomotive device. Therefore, further work towards this project would cause a greater long-term effect in advancing a better quality of life for all people.

ACKNOWLEDGEMENTS

The author is grateful to Universiti Tun Hussein Onn Malaysia and Universiti Malaysia Sabah for providing relevant resources in conducting this study. This work was funded under Tier 1 (HO66) and GPPS (HO53) Research Grants by the Research Management Centre, Universiti Tun Hussein Onn Malaysia. Communication of this research is made possible through monetary assistance by Universiti Tun Hussein Onn Malaysia and the UTHM Publisher's Office via Publication Fund E15216.

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