Time Series modeling and analysis of EEG Signal for wheelchair controller using Raspberry PI4

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ABSTRACT

This paper discusses a Wheelchair controller based on an EEG signal collected from a person using Mindwave mobile 2 and processed by a Raspberry pi.4.
A time series analysis was applied to build a statistical model to control a wheelchair with two DC motors.

Keywords: EEG Signal, Modelling, Time series Analysis, Wheelchair Controller, Raspberry Pi 4, DC motors drive, Mindwave mobile 2, Bluetooth.

1. Introduction:

This research builds a wheelchair control system using a mindwares mobile2 to measure the EEG signal of a person and a Raspberry Pi4 microcontroller to control a two L298N module DC motor driver, A time series method is used to analyze the signal and to build the statistical model.

Persons with physical disabilities or commonly known as a disability require special tools for doing their activities. Wheelchairs are one of the tools for the physically disabled especially the legs, to be able to move from one place to another, both on the flat and from a low to a higher place (point upward). The use of a conventional wheelchair still uses thrust motion with his fingers. It is less effective for persons with disabilities in moving the wheelchair because it requires considerable power to pedal a wheelchair using hand gestures. Moreover, when the user passes through an area that has a slope, the power is needed to be doubled as usual (Aniket) [1].

The control system of electric wheelchairs is different from the general industrial DC motor control systems. The control system of an electric wheelchair has many requirements so the wheelchair become comfortable and safe. the concrete requirements are the following:

1. DC motor used in a wheelchair is required to have a certain startup time and smooth process to remove the discomfort caused by inertia compared with the general DC motor. According to the results of psychological research, the start-up time should not be less than 5 seconds.
2. The overshoot is not permitted in the electric wheelchair when reaching high speed compared with the general DC motor control system.
3. The process of adjusting speed should have a certain time and is smooth enough without oscillation, which can supply comfortable feelings.
4. The control system should have a strong ability to anti-load disturbance.
5. The braking process time is the same as the startup must be less than 2-6 seconds (Ahmed) [2].

However, quadriplegic and paralyzed patients cannot use a conventional joystick controller. Thus, several new technologies, methods, and inventions have to be developed to serve this class of patients and to reduce their suffering. Nowadays, several input signals from the user's body can be used such as body gestures and motions, brain electrical signals, user voice commands, and electrical activity in the body muscles (EMG). Several approaches have been used for each signal. Each approach has its advantages and disadvantages (Mohammed & et.) [3].

Among these physiological signals, EMG, ECG, and EEG are the most important to be monitored because detailed measurement and analysis of the various electric signals produced by the body can supply vital medical predictions as to normal or pathological functions of the organs. Abnormal heartbeats can be readily diagnosed through electrocardiography. Electroencephalogram signals are interpreted by Neurologists to spot epileptic seizure episodes in patients. Signals from the muscles' activities can be helpful in assessing neuromuscular disorders through electromyography, and irregular movement of the eyes can be diagnosed using electrooculography. The processes required in the analysis of biomedical signals mostly consist of at least four stages (Ajani & et.) [4]:

i. Signals acquisition;
ii. Signals Conditioning;
iii. Computation of signal parameters that are diagnostically significant; and
iv. Interpretation or classification of the acquired signals

2. Basic Theory:

2.1 Electroencephalogram (EEG):

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 as to navigate the 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 (Bashar) [5].

To simplify the classification of the EEG signal, it is needed transformation signal that identifies and quantifies the EEG signal spectrum. EEG signals consist of alpha waves (8-12) Hz with conscious,

closed eyes and relaxed conditions, beta waves (12-30) Hz often arise when conditions are thinking or activity, theta waves (4-8) Hz occur when our circumstances being a light sleeper, sleepy or emotional system, and delta waves (1-4) Hz occurs when we are sleeping. The research used beta wave

frequency because the beta signal often raised when conditions were thinking and activity. The feature of the frequency band was the level signal and average of amplitude. Therefore, the representation of the EEG signal in the frequency domain is mostly done in research related to EEG signal analysis. Fig. (1) is an example of the EEG signals (Arzak) [6].

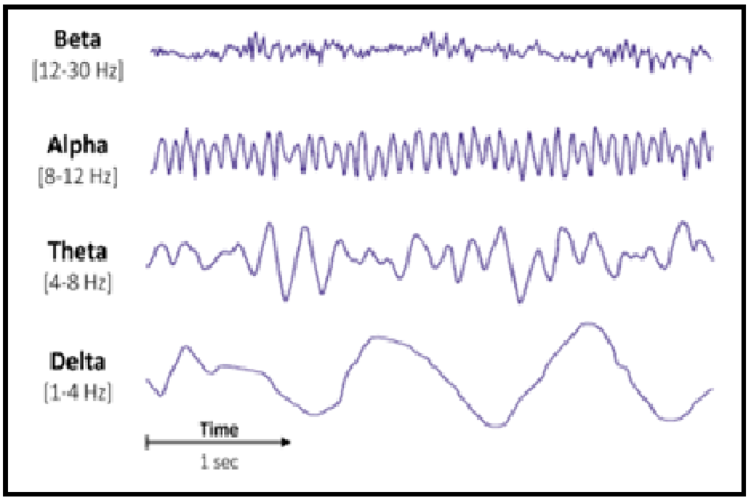

Fig. (1) example of the EEG signals

2.2 Mindwave Mobile 2:

Neuro Sky Mindwave Mobile 2 is a module for EEG acquisition based on the single lead electrode. Therefore, it only generated one signal EEG. Neuro Sky Mindwave is used to read EEG signal waveform. Where this device can communicate with other devices such as computers, laptops, and microcontrollers via a wireless network (Bluetooth). The shape of the Mindwave mobile 2 is seen in Fig. (2).

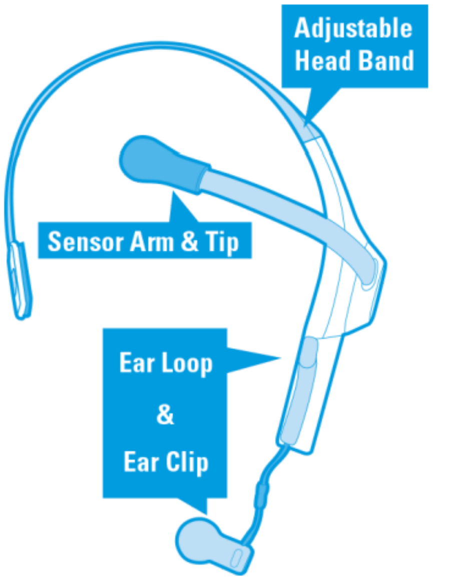

Fig. (2) Mindwave Mobile 2

2.3 Raspberry Pi4:

Raspberry Pi 4 Model B is the latest product in the popular Raspberry Pi range of computers. It offers ground-breaking increases in processor speed, multimedia performance, memory, and connectivity compared to the prior-generation Raspberry Pi 3 Model B+, while retaining backward compatibility and similar power consumption. For the end user, Raspberry Pi 4 Model B provides desktop performance comparable to entry-level x86 PC systems. This product's key features include a high-performance 64-bit quad-core processor, dual-display support at resolutions up to 4K via a pair of micro-HDMI ports, hardware video decodes at up to 4Kp60, up to 4GB of RAM, dual-band 2.4/5.0 GHz wireless LAN, Bluetooth 5.0, Gigabit

Ethernet, USB 3.0, and PoE capability (via a separate PoE HAT add-on). The dual-band wireless LAN and Bluetooth have modular compliance certification, allowing the board to be designed into end products with significantly reduced compliance testing, improving both cost and time to market, fig, (3) shows the raspberry Pi4 and it is pin configuration [7].

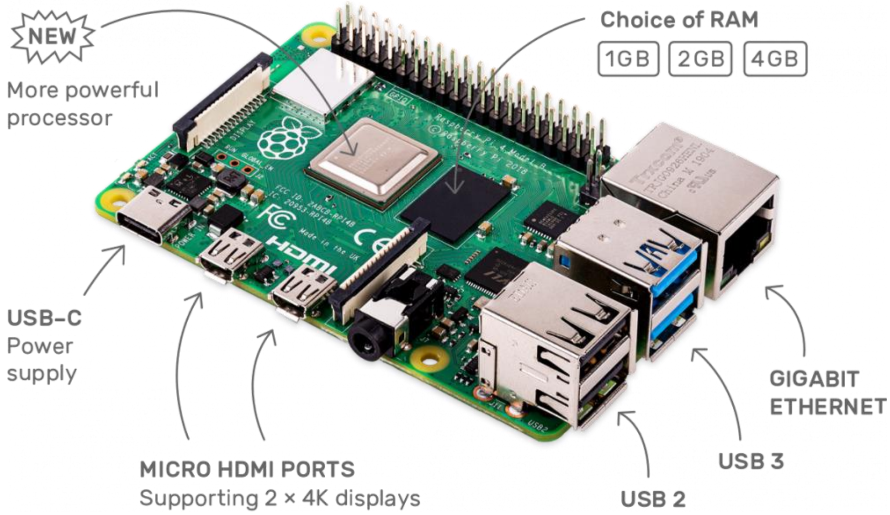

Fig.3 raspberry Pi4

2.4 Dc Motor Drive Module L298N:

The L298N Motor driver IC is powerfully built with a big heat sink. It is a dual-channel H bridge motor driver which can be easily used to drive two motors. The module also has a 78M05 5V regulator which is enabled through a jumper. Keeping the jumper intact, means the 5V regulator is enabled. If the motor power supply is less than 12V then we will power the module through the voltage regulator. The 5V pin in this case acts as an output to power the microcontroller. If the power supply is more than 12V, make sure the jumper is not intact and supply 5V power through the pin separately, L298N shown in fig. (4) [8].

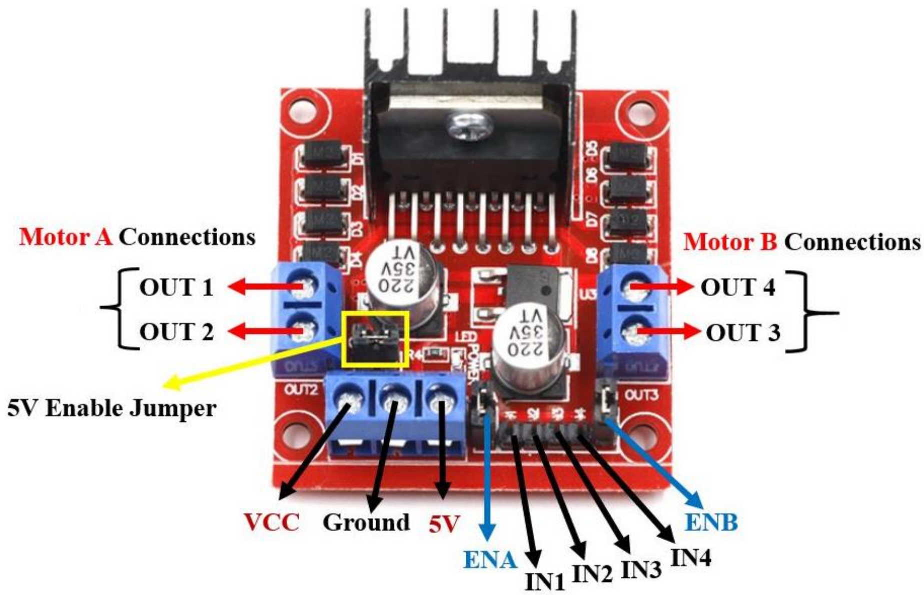

Fig. (4) L298N DC motor drive Module.

3. Time Series Analysis and Modeling:

The time series method is a forecasting method using an analysis of the relationship between the variables to be estimated and the time variable. Things that need to be considered in forecasting are errors that cannot be separated in the forecasting method. Forecasting results will be better if the error value is getting smaller. Time series data can be used as a basis for current decision-making, forecasting the state of time series data in the future, and planning future planning activities (Jurusan) [9].

The Holt-Winters method can be seen as a way to perform local regression, interpolating linearly the time series, but adapting the coefficients of the linear function, over time. The link between past and future, imposed by the recursive HW relations, constrains the dynamics of these coefficients, allowing the computation of the components. The HW method provides recursions for both trended and trended & seasonal time series; the latter model encompasses the former, but for didactic reasons, we introduce them separately, to clarify the ideas behind the approach (Susana) [10].

The initial value is the value used to estimate the initial value of the coefficients ($S0$; $b0$, I_k).

Initial values for additive model seasonal smoothing:

$$I_k = X_k - S_0 \quad (1)$$

with

I_k = Initial value for the k-season factor

k = Seasonal period (k = 1; 2; _ _ _ ;L)

The coefficients (α, ß, ɣ) have a distance between 0 and 1, determined subjectively, or minimize the estimate's error. The greater the number of constants, the forecasting process will take a long time because it will perform more iterations. This forecasting system will combine 3 (three) parameters to determine the best endless combination to produce the smallest MAPE and MSE.

The Holt-Winter method can handle seasonal factors and trends that appear simultaneously in time series data. The Holt-Winter method can be used for non-stationary data.

Additive models are used when there is no trend or sign that the seasonal pattern is dependent on data size. The equations used in the additive model are as follows:

$$St = \alpha (X_t - I_{t-L}) + (1 - \alpha) (S_{t-1} + b_{t-1}) \quad (2)$$

The equation for calculating the trend:

$$b_t = ß (S_t - S_{t-1}) + (1 - ß) b_{t-1} \quad (3)$$

The equation for calculating the seasonal smoothing in the additive model

$$I_t = ɣ (X_t - S_t) + (1 - ɣ) I_{t-L} \quad (4)$$

For the Holt-Winters exponential smoothing forecast value in the additive model, the following equation is used:

$$F_{t+m} = S_t + mb_t + I_{t-L+m} \quad (5)$$

with:

St = Exponential smoothing in observation t

S_{t-1} = Exponential smoothing in observation t-1

b_t =Smoothing trend elements in observation t

b_{t-1} = Element smoothing trend on observation t-1

X_t = Data t

α =Exponential smoothing parameter for data (0 < α < 1)

I_t = Seasonal factor smoothing

L =Seasonal length (L = 3, L = 4, L = 6 or L = 12)

F_{t+m} = Results of forecasting - (t + m)

F_t = The value wants to predict

m = The period to be predicted

ß = Exponential smoothing parameter for trend (0 < ß < 1)

ɣ = Exponential smoothing parameter for seasonality (0 < ɣ < 1)

The HW method can be seen as a way to perform local regression, interpolating linearly the time series, but adapting the coefficients of the linear function, over time. The link between past and future, imposed by the recursive HW relations, constrains the dynamics of these coefficients, allowing the computation of the components [9,10,].

4. Measurement and Control System:

This research built the EEG measurement system as shown in fig. (5), the Mindwave mobile 2 is connected to the Raspberry Pi4 computer through Bluetooth communication (BLE 5) which is built into both devices.

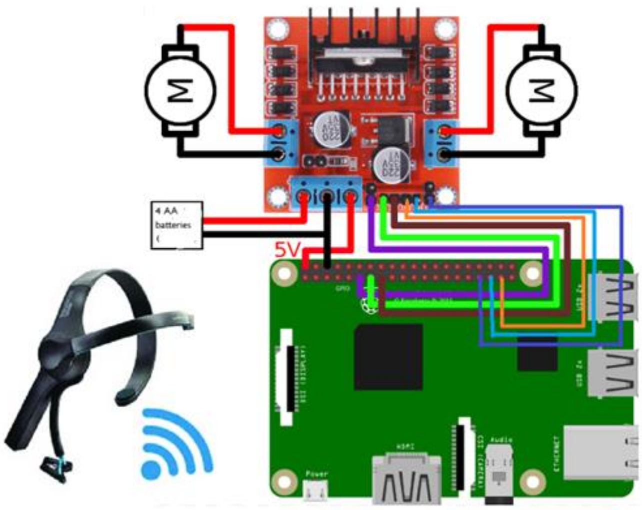

Fig. (5) EEG measurement system and DC motor controller

The raw EEG aw signal is measured and then processed by the Raspberry Pi4 to generate a suitable command to be sent to the L298N DC motor Module to move the wheelchair as required, the generated commands sent to the L298N are based on the statistical model of the EEG signal measured in this research.

5. Results and discussion:

The measured EEG signal was transformed into a time series data for analysis and model building, fig. (6) shows the plot of the EEG data as a time series. The main purpose of this transformation is to recognize a pattern in a particular time of measurement. They show similarity and a reputation, also varying from (1.2- 10 µV), and are Irregular, random movements, unpredictable, and uncontrollable in nature.

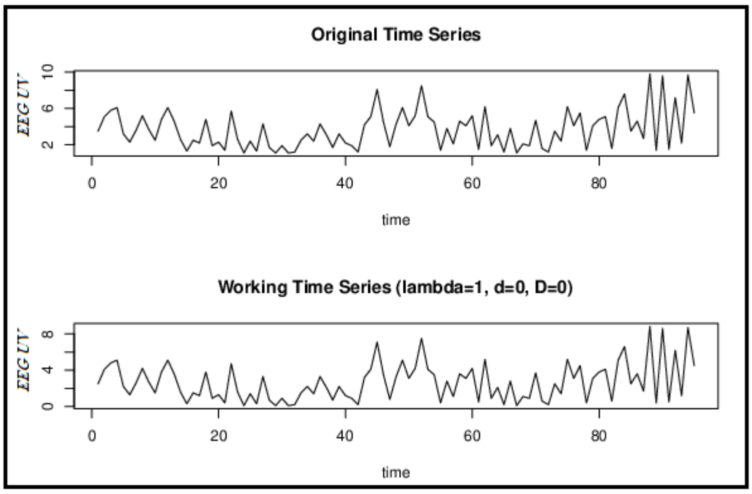

Fig. (6) Time series of the measured EEG signal

The autocorrelation plot of the EEG time series is shown in fig. (7). From the autocorrelation plot, we can see the degree of similarity between present-time data and it is past values, as known an autocorrelation of +1

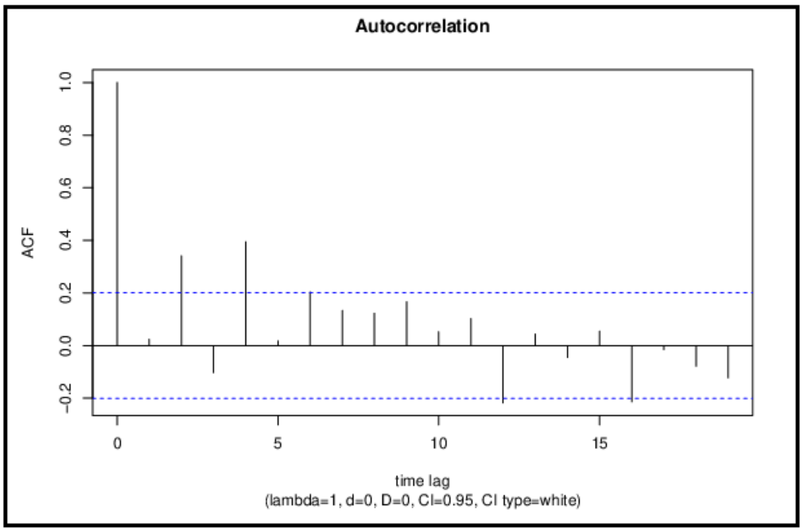

Fig. (7) Autocorrelation plot of the EEG data time series

Represents a perfect positive correlation, while an autocorrelation of negative 1 represents a perfect negative correlation.
From the plot, the autocorrelation is more than its threshold limit then the time series data possesses non-stationarity elements.

The forecasting results of the EEG data time series are shown in fig. (8), the plot shows the effect of taking seasonality into consideration on the resultant forecasting.

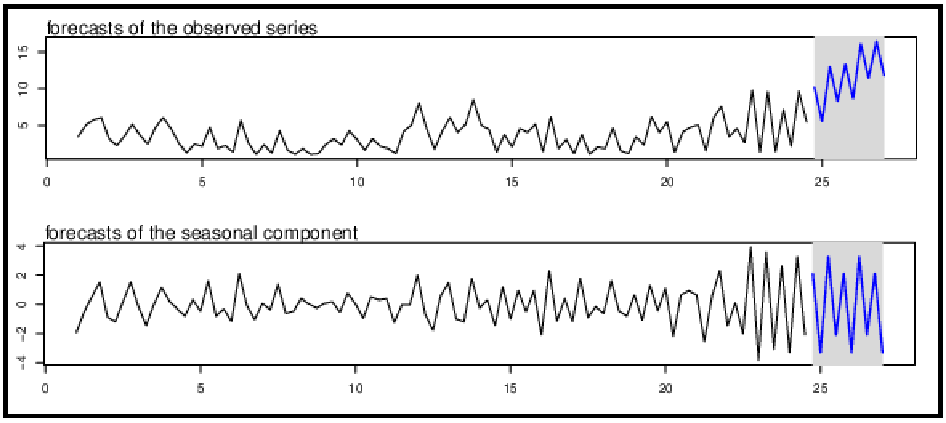

Fig. (8) forecasting plot of the EEG time series

This research applied a residual analysis for the built model, fig. (9) shows the plot of the standard residual.

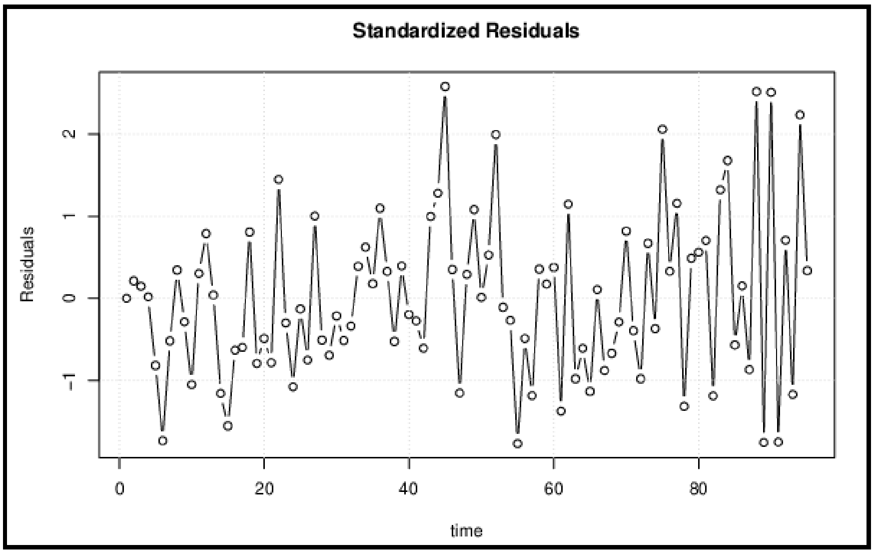

Fig. (9) Residual plot of the EEG time series

The first advantage of the residual analysis provides a clear idea about the correct initial specification of the model, also the residual analysis helps to remove noise from the model, in other words eliminating the uncorrelated components of data from the EEG time series. The residual histogram and the residual Kemel density are shown in fig. (10).

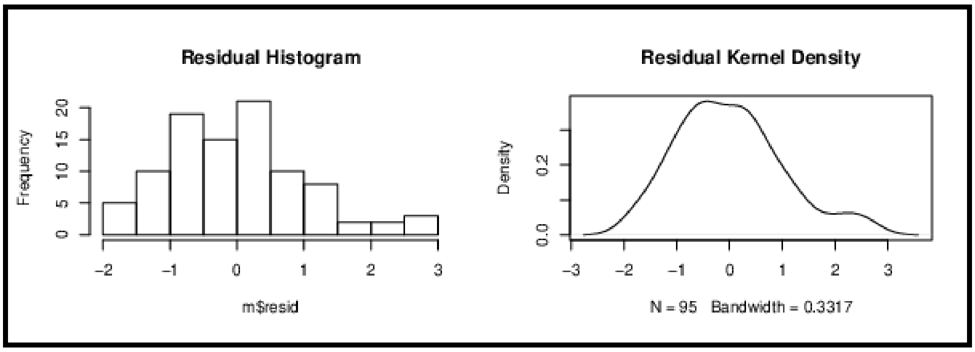

Fig. (10) Residual histogram and Kemel Density plot of the EEG time series

6. Conclusion:

This research presents statistical analysis and modeling of EEG signals using Time Series analysis, the model used to control a wheelchair. Measurements and a control system were built to collect EEG data and to control the wheelchair, a Mindwave mobile2 through Bluetooth communication will send the EEG data to a Raspberry Pi4 computer, and the EEG data transformed into a time series for analysis and creation of the statistical model.

The EEG time series was studied, flirted, and initial conditions calculated, and forecasted through an autocorrelation method and residual analysis process.

Two L298N DC motor drives connected to the Raspberry Pi4 output will be used to move the wheelchair, PWM output sent to the DC motors will help to reduce the power consumption and for better speed control.

The control system in this research shows reliability and confidence in use, also the control system can be improved easily by adding obstacle and line track sensors to give the ability of programmed path movements to increase wheelchair safety usage.

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