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Head Gestures Based Movement Control of Electric Wheelchair for People with Tetraplegia

M. A. Mohd Azraai, S.Z. Yahaya, I. Almanzo Chong,
Z.H. Che Soh, Z. Hussain, R. Boudville
Centre for Electrical Engineering Studies
Universiti Teknologi MARA, Cawangan Pulau Pinang
13500 Permatang Pauh, Pulau Pinang, Malaysia
aizat.azraai@gmail.com, saiful053@uitm.edu.my

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Abstract—**People who have suffered a spinal cord injury (SCI) may experience temporary or permanent loss of motor function, sensory function, and autonomic function. Tetraplegia patients are only able to move their upper body parts, such as the head, neck, and shoulder. They require wheelchair assistance to move around for their daily activities. The existing electric wheelchairs, on the other hand, rely on the users' upper arm for control which makes it difficult for the tetraplegia patients to control it. To address this issue, this project developed a control system in which control can be performed by head gesture. A gyro accelerometer is used to detect the user's head gesture. A microcontroller connected to the sensor will read the data and translate it into instructions to control the movement of the electric wheelchair based on the pre-defined head motion patterns. To obtain an average test result of the system's functionality, the system was tested on a healthy adult subject. The average maneuvering error of the trial run using electric wheelchair model on the smooth surface was 3.18cm and an average 5.2cm on the rough tar road surface. Thus, the developed control system can be assumed to be effective in detecting head gesture and that it accurately maneuvers the electric wheelchair according to the head gesture pattern.**

Keywords— Head Gestures, Gyro Accelerometer, Electric Wheelchair, Microcontroller

I. Introduction

Tetraplegia, also called quadriplegia, is a type of paralysis that affects all four limbs as well as the torso (the word "quad" comes from the Latin word "four"). Tetraplegia causes considerable paralysis below the neck where in many cases, many people are unable to move at all. Damage in the higher section of the spinal cord, commonly in the cervical spine between C1 and C7, causes this type of paralysis. The more serious the injury, the more severe the damage. In fact, injuries to the C1 and C2 vertebrae of the spinal cord frequently result in death due to the disruption of breathing and other vital functions. [1]

Living with tetraplegia can cause great difficulty that necessitates considerable lifestyle changes for both the tetraplegics and those around them. Tetraplegics who lack control of their arms and legs rely on others to help them to get around, go to the restroom, eat, and perform other everyday routines. Tetraplegics may be able to operate their wheelchairs with head motions in some motorized wheelchairs, although it may take some getting used to. [1]

Many studies have been conducted to create a control system to help tetraplegia patients with controlling the electric wheelchair. Dahmani et al. [2] and Aniwat Juhong et al. [3] conducted research on controlling the wheelchair using eye tracking where they used image processing to detect the direction of the eye pupil to determine the motion of the wheelchair. Other than that, there were studies conducted by Dev et al. [4] and Tanaka et al. [5] which integrate brain wave signals to control the electric wheelchair. The studies used electroencephalogram (EEG) concept in measuring electrical activity of the brain and converted it into a command signal.

The mobility of tetraplegic patients who are paralyzed from the chest down is constantly a concern for their everyday lives. The usage of an electric wheelchair may aid them in moving around. However, existing electric wheelchairs in the market rely on the users' upper arm for control, leaving many details to be developed. Researchers have recently focused on methods such as face tracking [2], eye tracking [3], and EEG-based brain control [4] to develop alternate means of controlling electric wheelchairs. However, some approaches are difficult to implement, they suffer from processing delays, and produce unstable signals owing to noise, among other issues. Eventually, this makes the wheelchair expensive and inaccessible to some people. There were many previous studies related to head gesture control conducted, essentially using image processing to detect head gesture [6][7], accelerometer [8] and gyro-accelerometer [9] [10].

The use of wheelchairs has risen rapidly in recent years as the population has aged and the demands from handicapped people have increased. Disabled persons with physical disabilities experience a difficult time since they rely on their caregivers for assistance, especially in terms of mobility. An appropriate wheelchair is a pre-requisite for survival and personal mobility [11]. Thus, the present study proposes a control system for electric wheelchairs that is tailored to the needs of certain groups of impaired individuals. The project's output is anticipated to increase impaired people's movement independence and, as a result, their quality of life will be improved. They will be able to resume their everyday routines and enjoy their preferred pastimes owing to reduced movement limits. This initiative is also intended to contribute to the progress of electric wheelchair control techniques and serve as a starting point for further research in this area.

In this work, a head gesture-based electric wheelchair movement control system utilizing a 3-axis gyro accelerometer sensor was developed. The gyro accelerometer GY521 MPU6050 was chosen as the main component for the head gesture sensing for the system. The signal was applied to the head gesture accelerometer and then processed by the microcontroller and transmitted to the electric wheelchair via radio frequency transceiver module nrf24l0. The performance of the system was evaluated based on its accuracy during movement on smooth and rough surfaces. This system may offer some contributions in terms of minimizing the risk of inaccuracy during maneuvering if compared to the systems with complex techniques such as Brain Computer Interface (BCI) and voice recognition.

II. METHODOLOGY

The system was designed and developed to achieve the ability to track head gestures, perform processing of data and produce an accurate control instruction to control the movement of the electric wheelchair. The system operation involves a few steps. Fig. 1 presents the flow of the system operation.

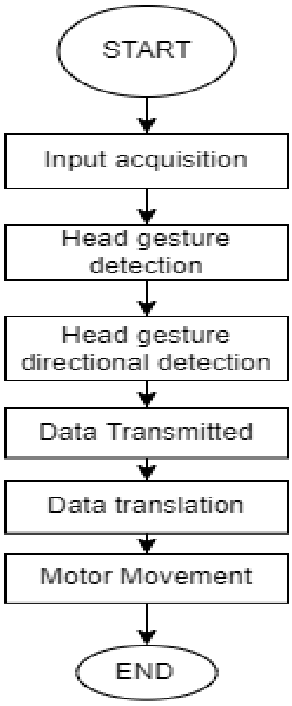


Fig. 1 Steps of System Operation

The system basically consists of two main subsystems which are the Sensing Unit and the Electric Wheelchair Model.

A. Sensing Unit

The Sensing Unit was built using several components such as accelerometer, gyroscope, processing unit, and transceiver. It uses a GY-521 MPU6050 6DOF Accelerometer + Gyro that integrates a 3-Axis Gyroscope and a 3-Axis Accelerometer, allowing measurements of both independently, but all are based on the same axes, thus eliminating the problems associated with cross-axis errors when using separate devices. This MEMS type sensor has been quite common for measuring tilt angle along an axis [12].

The microcontroller used is the Arduino Nano which acts as the processing unit. Its small size and light weight factors are the reasons for it to be selected. Fig. 2 displays the Sensing Unit which is attached on top of a hat for easy fit for users. The Sensing Unit also consists of the nRF24L01 + wireless module 2.4G that functions as a wireless transceiver module that communicates the Sensing Unit to the Electric Wheelchair Model.

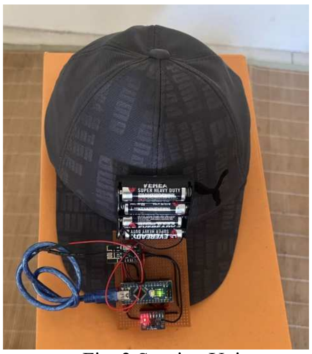


Fig. 2 Sensing Unit

B. Electric Wheelchair Model

In this project, a small-scale model of an electric wheelchair was built to imitate the functions of an actual electric wheelchair. The Electric Wheelchair Model was used to analyze the overall system function starting from the sensing until the controlling and maneuvering functions. Fig. 3 presents the Electric Wheelchair Model.

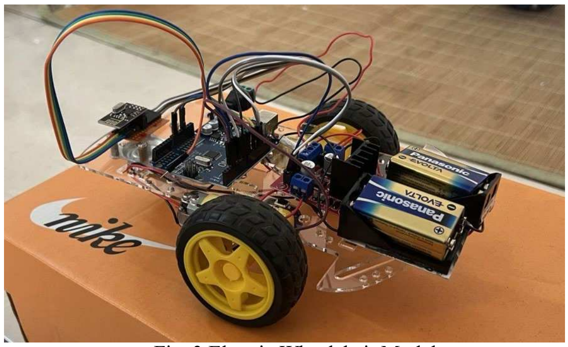


Fig. 3 Electric Wheelchair Model

The Electric Wheelchair Model is a small mobile platform with two rear wheels and is driven by a two-geared DC motor. The mobile platform is also supported by a castor wheel at the front section to stabilize it during movement. This Electric Wheelchair Model is expected to provide approximately the same responses as an actual electric wheelchair would since an actual electric wheelchair is also driven by two-rear wheels and DC motors.

The Electric Wheelchair Model uses an Arduino UNO as the microcontroller. L298N which is a dual channel motor driver is used to control the two motors. The motor driver has a maximum current output of up to 2A per motor which is sufficient for its load in this application. The Electric Wheelchair Model is also equipped with the nRF24L01 + wireless module 2.4G transceiver similar to the Sensing Unit to achieve stable connectivity between both subsystems.

C. System Operation

Fig 6 shows the system's block diagram, which depicts the flow of the operations from the input to the output. Initially, the head gesture motion is to be performed by the user and the MPU6050 will start performing the calibration of the initial position of the sensor. When a stable initial position of sensor is set, the MPU6050 begins detecting the user's head gesture based on Pitching and Rolling motion data.

Data processing is performed in the microcontroller and wirelessly transmitted to the Electric Wheelchair Model. The receiver on the Electric Wheelchair Model then collects the data and sends it to the microcontroller for processing to decide which movement direction suits the data. Matching between the Pitching and Rolling data and the control instruction (wheelchair movement direction) are shown in TABLE I.

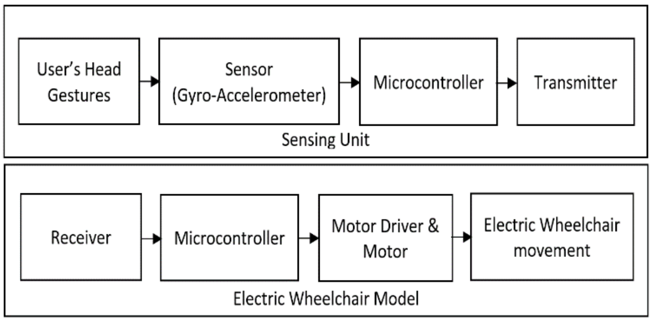


Fig. 4 Block Diagram of the System

TABLE I PITCHING/ROLLING DATA AND MOVEMENT

Direction	Motion	Axis		
		X	Y	X
Forward	Pitching	Increase	Maintain	Maintain
Backward		Decrease	Maintain	Maintain
Left	Rolling	Maintain	Decrease	Maintain
Right		Maintain	Increase	Maintain

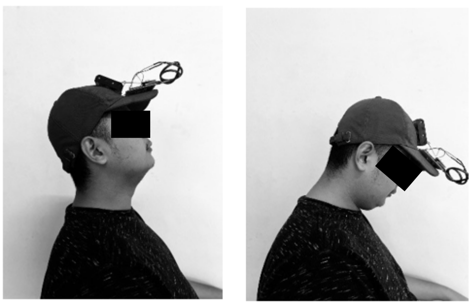
D. Head Gesture

The initial or steady state position of the head occurs when the user's head is at the horizontal level as shown in Fig. 5 (a) and (b). At this state, the angle of the sensor will be at 0°.

(a) (b)

Fig. 5 (a) Side View (b) Frontal View

When the user looks upward at 35º(Fig. 6 (a)) from the center point, this will result in a reverse action of the electric wheelchair. At the opposite direction of looking downward at an angle of -35º (Fig. 6 (b)), the wheelchair will move forward. The motion can be related to a pitch motion of the nose of an airplane pointed upward and downward.



(a) (b)

Fig. 6 Pitching Motion: (a) Looking Upward (b) Looking Downward

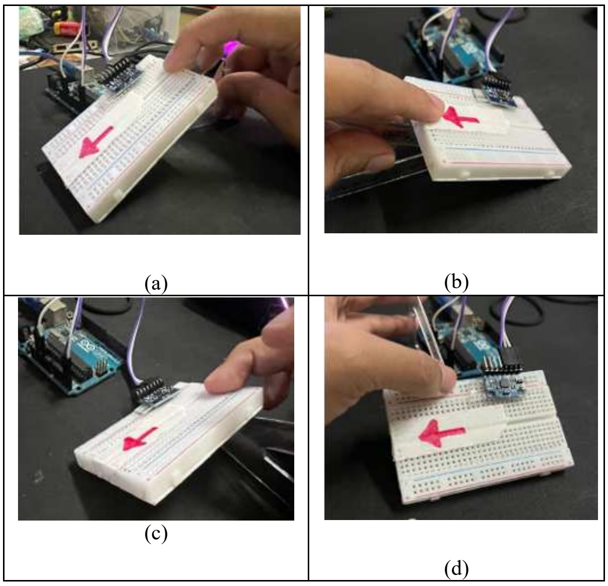
When the user bends their head 35º (shown in Fig 7 (a) and (b)) to the left and then to the right, this will cause the electric wheelchair to turn left or to turn right.

(a) (b)

Fig. 7 (a) Head Turning Left (b) Head Turning Right

E. Sensor Callibration

Simple sensor calibration was performed on the GY-521 MPU6050 as shown in Fig 8. The calibration was conducted to ensure the sensor will provide an accurate reading. The calibration was implemented by using the right angle ruler of 30º as the reference point for the sensor to detect a 30º orientation for forward motion (see Fig 8(a)), backward motion (see Fig 8(b)), lean to right (see Fig 8(c)), and lean to left (see Fig 8(d)).



(a) (b) (c) (d)

Fig. 8 (a) Forward Motion (b) Backward Motion (c) Lean to Right (d) Lean to Left

F. Straight Line Maneuver Test

The accuracy of the electric wheelchair maneuvering through a straight line track was also tested. The test was performed on two different surfaces which are on the smooth tile surface to test the indoor situation, and on the rough tar road surface for outdoor situation. The electric wheelchair needed to maneuver on a 2.5m straight line. There were five checkpoints that were 0.5m apart from each other. The checkpoints were where the data of maneuvering error were taken. Testing setup is displayed in Fig. 9 for smooth tile surface and as demonstrated in the figure, the same setup was used for tar road surface.

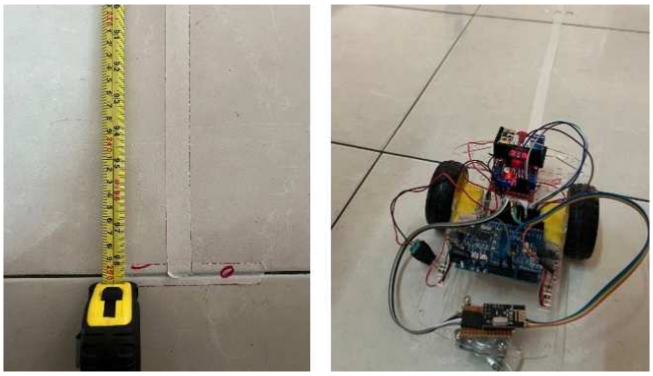


Fig. 9 Testing Setup

III. RESULT AND DISCUSSION

Two tests were conducted to analyze and evaluate the performance of the system in producing accurate movement. First, a calibration was performed to ensure the accuracy of the angle taken by the sensor. The calibration technique is explained in section *II* E. Each directional motion serial monitor reading was taken and TABLE II presents the average serial monitor reading for each motion.

TABLE II AVERAGE SERIAL MONITOR READING

	Average Serial Monitor Reading		
	X	Y	Z
Forward	30.62	0.03	-9.05
Backward	-29.97	-2.03	-40.16
Right	3.51	-27.94	-46.07
Left	-2.07	28.66	-46.78

Based on the data obtained, it can be summarized that for the X- axis, there is a ± 0.6 error margin when the sensor tilts forward and backward. For the Y-axis, there is a ± 2 error margin when the sensor is tilted toward the left and right.

Furthermore, the electric wheelchair was tested for its ability to be controlled on two types of surfaces. The average maneuvering error of the electric wheelchair from the straight line was recorded. The test was conducted in ten trials for both surfaces. In each trial, the test subject was asked to try maneuvering in a straight line and to stop at each check point which was set at every 0.5m interval.

At every check point, the maneuvering error of the electric wheelchair from the reference line was measured. This can be viewed in TABLE III and TABLE IV. The average error was recorded and plotted onto a line graph as depicted in Fig 10 and Fig 11. Based on the recorded data, it is revealed that the system was able to properly maneuver on both surface types. As shown in Fig. 10, better maneuvering was recorded after the third trial. This might be contributed also by better stability of the Electric Wheelchair Model itself when moving on a smooth surface as compared to a tar road surface (Fig. 11). However, if an actual wheelchair is used, it seems to be less effected by the tar road condition due to its wheel size. What is important to highlight in this analysis is that the head gestures have been successfully translated into the right instructions to control the movement of the Electric Wheelchair. Performance may differ from one user to another. However, with frequent usage and training, they will gain better control of it.

TABLE III TRIAL RUN DATA ON SMOOTH SURFACE (TILE)

Trial Run	Error at Check Point				
	1	2	3	4	5
1	12	10	6	5	2
2	20	8	9	2	7
3	3	2	4	7	3
4	0	3	3	2	3
5	2	3	3	1	0
6	0	3	1	1	3
7	1	3	2	2	3
8	1	2	4	2	1
9	2	2	3	0	0
10	0	1	2	0	0

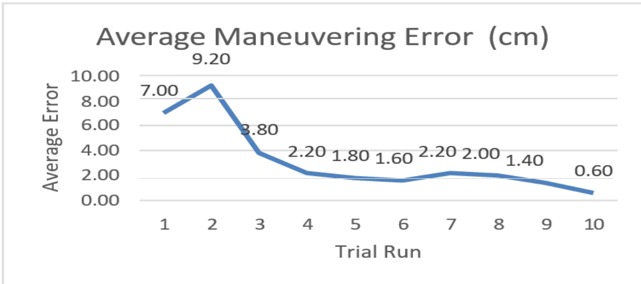


Fig. 10 Average Maneuvering Error on Smooth Surface (Tile)

TABLE IV TRIAL RUN DATA ON ROUGH SURFACE (TAR ROAD)

Trial Run	Error at Check Point				
	1	2	3	4	5
1	13	9	4	3	7
2	10	1	3	5	5
3	5	3	1	3	4
4	3	5	2	7	6
5	4	0	5	3	2
6	13	3	5	10	6
7	6	2	1	1	3
8	15	4	1	7	9
9	16	6	2	6	7
10	10	5	5	3	1

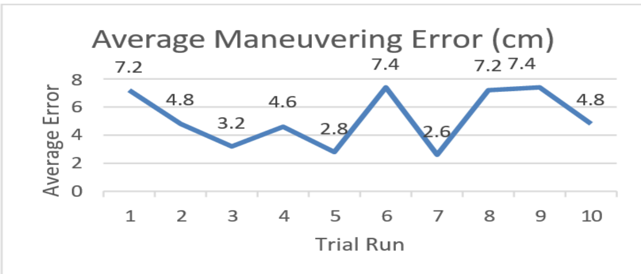


Fig. 11 Average Maneuvering Error on Rough Surface (tar road)

IV. CONCLUSION

This work outlines the design and development of a head gesture-based electric wheelchair control system utilizing a small-scale prototype that might be expanded to a real electric wheelchair. The wheelchair may be tailored to the patient's requirements by adjusting the threshold values for head tilt along the X and Y axes. Furthermore, the project proves that the model could operate when considering the characteristics and functionalities of an actual full-scale electric wheelchair, as well as the many conditions in which the electric wheelchair may operate. For a recommendation for future studies, additional artificial intelligent features can be implemented to ensure a better performance of the system.

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