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The dynamic behavior investigation of electric power wheelchair during the obstacle avoidance

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The dynamic behavior investigation of electric power wheelchair during the obstacle avoidance

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Abstract. The increment of the People with Disabilities (PWDs) keep increasing in each year and an urge of assisting these PWDs is demanding. Commercial manual wheelchair eases the mobility of the PWDs but there is side effect for the manual wheelchair users that is pain on shoulder area due to extensive daily propulsion of manual wheelchair for mobility. Therefore, this paper presents an approach towards the autonomous wheelchair whereas concerning the PWDs that have disabilities from upper to lower limbs. These paper investigates the dynamic behavior of the autonomous wheelchair during the obstacle avoidance. The experiment conducted on the Electric Power Wheelchair (EPW) and several participants divided base on gender and age for this particular investigation. This experiment uses the EPW as a first step before taking next step towards self-navigation system in order to understand the behavior of the autonomous wheelchair by using the intervention of human input on EPW. The participants will maneuver the EPW via joystick with several speed justifications that is determined during the pre-experimental set-up. This study focused on the changes in speed of both left and right tires and yaw angle during the obstacle avoidance. The data will be used as a reference for the autonomous wheelchair during the obstacle avoidance. The data that maneuvered manually by the participants also serve as the human-machine relationship whereas the data will be interpreted into the control systems that will be developed for the autonomous wheelchair. Based on the results, the changes of velocity could be seen from both left and right tires during the obstacle avoidance base on gender is different but the trend of the results significantly same for both male and female.

Keywords. Electric powered wheelchair; Obstacle avoidance; Dynamic behaviour, Human-machine relationship; Tires velocity.

1. Introduction

Malaysia achieved independence in 1957 and has committed to itself to improve both economic growth and the human aspects of development. This is aligned with Malaysia's Vision 2020, which aims to attain the status of a fully developed nation with equal emphasis on enhancing the wellbeing and the social stability of the people and the establishment of a fully caring society. Malaysia's policy and programmes of the disabled citizens of the country are guided by the strategic goals of the National Welfare Policy, which emphasizes on the attainment of self-reliance, of opportunities for the less fortunate and fostering of the spirit of mutual help and support towards enhancing a culture caring [1].

According to the statistic provided by the World Health Organisation (WHO), it is estimated that 5-10% (1.3-2.6 million) of the word populations are people with disabilities (PWDs). As reported by the

Department of Statistics Malaysia, the total population of Malaysia in 2006 was 26.64 million people and from this statistics, 1.3-2.6 million are PWDs. However, as of December of 2007, only 220 to 270 PWDs were registered with the Social Welfare Department. This number is predicted to rise along with the increasing population, lifespan and the total number of road and industrial accidents. Malaysia is expected to increase from 1.73 million (6.6%) in 2005 to 3.8 million (11.3%) in 2020 [2].

Even though, the people with disabilities are protected by the National Welfare Policy but the challenges for the disable people in the workplace still exist. Several studies have shown that bias or discrimination in hiring PWDs is still rampant throughout the world. Most of the study stating that PWDs are often viewed negatively [3]. In another study, the PWDs also facing the problem of discrimination and exploitation at work [4]. However, despite the bias in the workplace, PWDs is still accepted for work. About 3000 persons with physical disabilities are employed in the private sector and 540 in the public sector in Malaysia [5].

In order to aid the PWDs, manual wheelchair was designed to aid the mobility of PWDs for their daily life routine. The use of manual wheelchair suitable for a user's individual characteristics and needs can improve their independence, sense of participation and quality of life [6]. Studies has stated that, different wheelchair configuration could impact the biomechanics of manual propulsion. Rear wheel's vertical and horizontal position, and wheel size and camber have been shown to affect propulsion efficiency and wheelchair drivability [7]. In order to overcome this problem, researchers suggest that moving the wheels slightly forward will improve the propulsion. The effect of this will increase the push angle and shoulder range of motion (ROM), thus reducing both push frequency and hand rim forces results in minimizing the risk of upper limb injuries [8].

Even though, all the method for the suggested to reduce the injuries during the propulsion of manual wheelchair, the long term injuries for the manual wheelchair user still the same for the period of time especially in the shoulder area [9]. The development of the smart wheelchair helps the adult and children with disabilities for their independent mobility and thus increase the self-esteem aspect [10]. The development of smart wheelchair not only aids the mobility independency but also gives comfort in achieving daily routine in their life. The advance development of the smart wheelchair also aids the people with disabilities that cannot use the traditional joystick to navigate their power wheelchair. Instead of using the traditional joystick, power wheelchair user uses alternative head joystick, chin joystick, sip-n-puff, and thought control [11, 12]. In order to ease the movement of the PWDs that loses all of the upper and lower limbs, researchers developed an autonomous wheelchair that self-navigated for outdoor and indoor environment with the aid of light and ranging (LIDAR) sensors that eliminate the global positioning (GPS) method [13].

Some of the smart wheelchairs consist from the manual wheelchair itself but being adds on with the control system and a various of sensors that functiones as the navigational purposes or health monitoring for the users [14].

2. Electric power wheelchair

This section providing the pre-information regarding the EPW that will be used in the experiment. This EPW equipped with joystick as shown in figure 1(a) for maneuvering purposes with two DC motor attached on each of the tires. The EPW also installed with the two free rolling wheel or castor wheels in front of the EPW as depicted in figure 1(b). The wheel could rotate in 360 degrees to ease the mobility and maneuvering the EPW.

Figure 3 show the basic measurement of current commercially use electric powered wheelchair. All of the specifications from the table 1 and table 2 are directly from the manufacturer. For the experiment some modification has been made on the EPW in order to ease the installation of the sensors that will attached to the EPW. The modifications that made on the EPW does not affect the performance and mechanical abilities of the EPW. It is to ensure that the data taken will be not affected from this modification. The modification can be seen on the methodology.

(a) (b)

Figure 1. The electric power wheelchair.is equipped by (a) The joystick with speed control and (b) The 360 degrees castor wheel.

Figure 2. The commercial EPW that used nowadays with the measurements.

Table 1. Shows the specifications and the capability of the EPW given from the manufacturer of this EPW.

Specifications	Capabilities
Motor Power	250W per motor
Climbing Ability	<13 Degree
Battery	24V,12A
Battery Endurance	10-15 Km
Speed Mode	6 Speed Adjustment

Table 2. Shows the brand name, the model, wheel size, weight, and the specified users that can use the EPW given from the manufacturer.

Specifications	Measurements
Brand	Jikang
Model	TW100
Wheel Size	10 Inch(Front), 22 Inch (Rear)
Weight	34 Kg (Without battery)
User	Elder and disables

3. Methodology
The methodology of this experiment will explained from the modifications of the EPW until the experimental set up in order to acquire the data needed for the autonomous wheelchair.

3.1. Electric power wheelchair set up
Without any modifications that must be made on the EPW, it will be extremely difficult to attached the sensors to acquire the data. The modifications of the EPW are made on the frame without affecting the electrical and mechanical system of the EPW. Some extensions are made such as additional frames as shown in figure 3 must be placed on the EPW enabling the installation of the sensors can be made. Figure 4 shown the EPW appearance after the modification are made. The comparison can be seen from the figure 1 and figure 3 and 4 whereas figure 1 does not have the additional extension while the latter figures have the additional extension that consist of T-profile frame with the specifications 2cm x 2cm.

Figure 3. The additional frame attached to the frame of the EPW for the sensor installation purposes.

Figure 4. The EPW appearance after some modifications is made in order to ease the installation of the sensors.

3.2. Sensors
The sensors that utilized in this experiment are rotary encoders (installed in both right and left tires) and gyroscope. Rotary encoders functioned to collect the velocity of right and left tires. The gyroscope used to determine the changes in Yaw-angle when the EPW make a turn during the obstacle avoidance.

3.2.1. Rotary Encoder. The rotary encoder installed within the center of the tire in order to collect the data of the speed of the both right and left tires as depicted in figure 5. The specification of the rotary encoder listed in table 3.

Figure 5. The position of rotary encoder installed on EPW.

Table 3. The specifications of the rotary encoder for both right and left tires.

Specifications	Details
Type	Incremental type shaft encoder
Operating Voltage	5V to 24V
Pulse	500P/R
Slew Speed	6000RPM
Body Diameter	25mm
Shaft Diameter	4mm
Output Wave Form	Square Wave
Brand	ESB, Japan

3.2.2. Gyroscope sensor. Some additional frame must be placed on the EPW so that the gyroscope sensor could be installed. The red circle as being shown in the figure 6 shows the location of the gyroscope. The gyroscope installed at the center of the wheelchair in order to detect the changes in Yaw-angle of the EPW during the navigation. The data that is crucial for the experiment is the turning angle of the EPW during the obstacle avoidance. Table 4 listed the specification of the mentioned gyroscope sensor.

Figure 6. The position of gyroscope sensor being installed on EPW.

Table 4. The specifications of the gyroscope sensor.

Specifications	Details
Drift Rate	1 deg/s
Noise	0.05 deg/s
Bandwidth	40 Hz
Misalignment	0.1 deg

3.3. Data Logging System

Data logging system is important to store the data from the rotary encoders and the gyroscope. Without the data logging system, the analysis of data will be quite impossible. The data logging system that being used in this experiment is the Myrio in the platform of National Instrument by using LabVIEW 2013 as the interface and for encoding the data logging system. Figure 7 show the position of Myrio being installed on EPW.

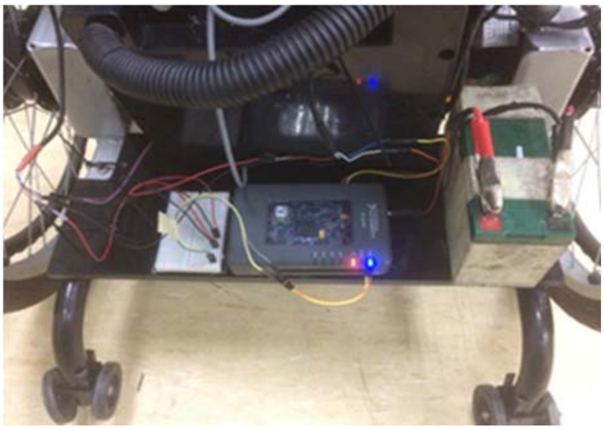

Figure 7. Shows the location of the Myrio behind of the EPW.

As being mentioned, the data logging system that being used for the experiment on the platform of National Instrument. Myrio also could act as the embedded control system. The specifications for the Myrio can be seen from the table 5 as shown below. Myrio that being used for this experiment is the Myrio 1900.

Table 5. The specifications of the Myrio 1900.

Specifications	Details
Processor	Xilinx Z-7010 processor 667 MHz (ARM Cortex A9 x2 cores 28nm process NEON SIMD, VFPv3 Vector Float)
Memory	NV: 256 MB, DDR3 512MB, 533 MHz, 16 bits
Processor Type	FGPA
Wireless Connection	IEEE 802.11 b, g, n ISM 2.4 GHz 20 MHZ
Port	2 Ports of 16 Digital I/O Lines
Accelerometer	3 Axis Accelerometer
Power Consumption	14 W

Table 5 shows the specification of the Myrio 1900 that being used in the experiment. Myrio 1900 interfaced with the LabVIEW 2013. From LabVIEW 2013, the users could encode the programming system for data logging system.

The block diagram in figure 8 shows on how to determine the speed for both right and left tires. From this block diagram, the accumulated travelled distance also can be determined. Meanwhile, figure 9 shows the block diagram of the rotary encoder where the connection between this block diagram (encoder) and the rotary encoders (sensor) must be correct.

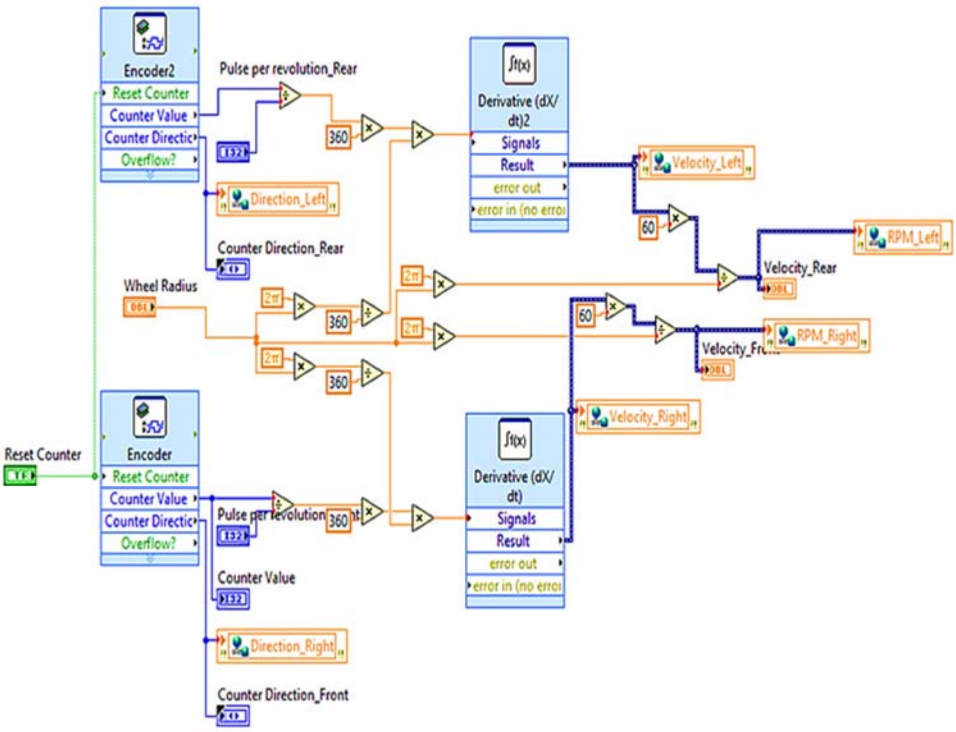

Figure 8. The block diagram of data logging system.

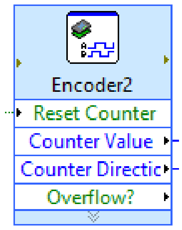

Figure 9. The block diagram that represents the rotary encoder.

Table 6 represents the connection between Myrio and rotary encoders. The Myrio will be interfaced with the LabVIEW in obtaining the data.

Table 6. The connection between Digital I/O of LabVIEW and Myrio to the rotary encoder.

Block diagram and rotary encoder connection	
Encoder 1	Right Rotary Encoder
Channel	A/ENC
Connection	Phase A: Pin 18, Phase B: Pin 22
Encoder 2	Left Rotary Encoder
Channel	B/ENC
Connection	Phase A: Pin 18, Phase B: Pin 22

3.4. Experimental set up

3.4.1. Participants. In order to ensure the safety of the participants, the experiment conducted under a closed area which the path for the obstacle avoidance is already pre-determined. The participants that take part in this experiment are the students of Universiti Malaysia Pahang. Table 7 shows the information regarding the participants for this experiment. The age of the participants ranges in between 20-25. The weight of the participants also must be considered due to the wheelchair has the load limit and if the limit exceeds, some of the data will be affected.

Table7. Participants' information.

Participants	Details
Numbers	5 (Man) and 5 (Woman)
Age	20-25
Weight	<80 Kg

3.4.2. Layout of the experiment. Before an experiment is being conducted, some measurements must be taken care of. Thus some lay out is design that act as reference in keeping the all of the measurements is being kept constant. Such as the distance that need to be travelled by the EPW and location of the obstacle also must be kept constant to preserve the trend of the data.

The participants will be provided with the layout that act as the guidance in order to give the consistency in the data. The layout can be seen from the figure 10

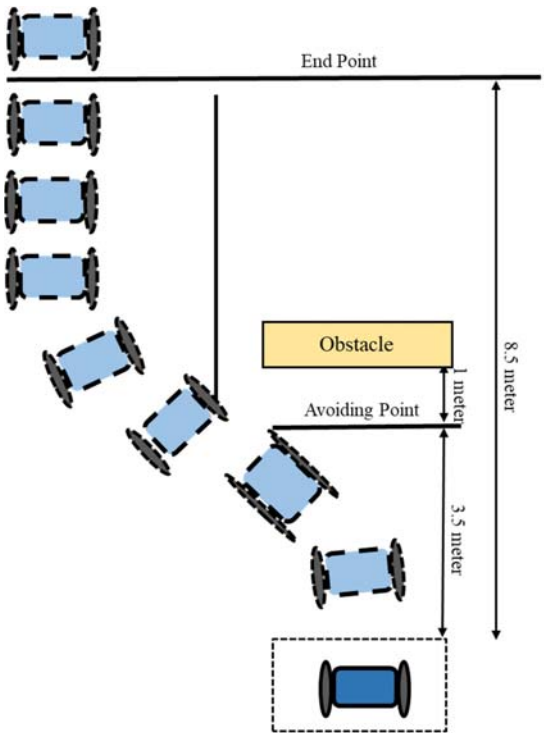

Figure 10. The layout for the experiment that will be conducted.

The object in the dotted rectangle is the EPW while the dotted rectangle is the starting point for each of the participants to start navigating the EPW. Each of the point is already separated by the distance that have been decided before the experiment started. As being mentioned, the obstacle will be kept constant to preserve the trend of the data.

The distance from the starting point to the avoiding point is 3.5 meter. The distance from the avoiding point to the obstacle is 1 meter. The distance from the starting point until the end point is 8.5 meter. The participants are needed to avoid the obstacle before reaching the avoiding point and stop at the end point as being shown in the figure above. The reading will be taken for three times for each of the participants. The data will be separated according to the gender. The data will be tabulated translated into the graph to see the different between maneuvering style of man and woman. The main focus is to see the changes in speed during the obstacle avoidance and the behavior of the wheelchair during the situation. The data is taken in two different speed only due to safety precautions.

4. Results

After the experiment conducted, the data of the speed and the Yaw angle is acquired. The data is collected and tabulated for the analysis purposes.

The data is analyzed based on the gender to see the trend between the man and woman when maneuvering the EPW. The reading is taken based on the participant's experience and comfort. The results only based two different speed due to the safety concerns toward the participants.

4.1. First Speed = 0.8 ms^{-1} (with load)

The first speed that being experimented is at 0.8 ms^{-1} that is load with the participant. The results divide into two which are based on gender male and female student.

4.1.1. Participants = Male Student.

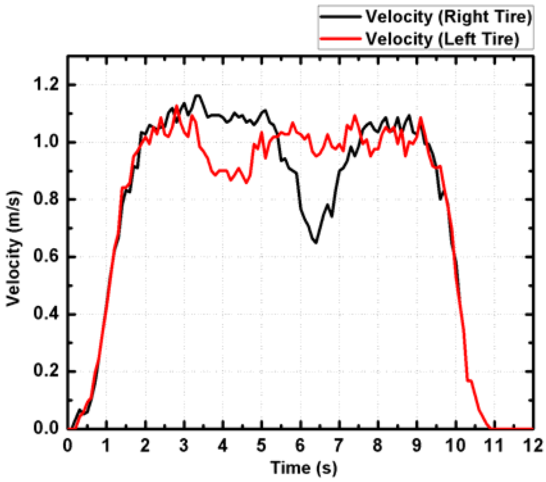

Figure 11. Velocity of right and left tires against time during the experiment for male student.

Table 8. The maximum and minimum velocity of right and left tires of EPW for male student.

Max and Min Velocity	Right Tire	Left Tire
Maximum (ms^{-1})	1.16	1.12
Minimum (ms^{-1})	0.05	0.04

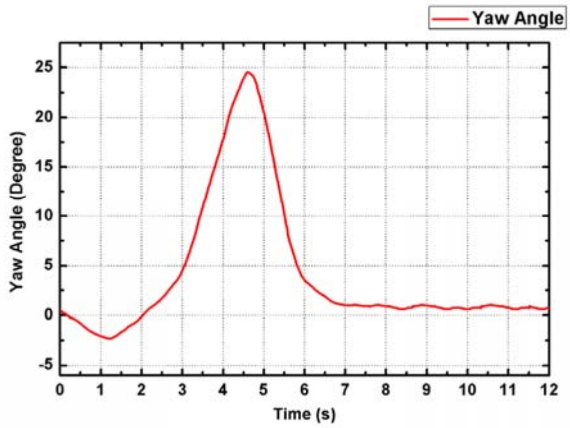

Figure 12. The changes in Yaw angle against time for male student.

Table 9. Maximum and minimum Yaw angle of EPW

Max and Min Yaw Angle	EPWe
Maximum (Degree)	24.49
Minimum (Degree)	-2.30

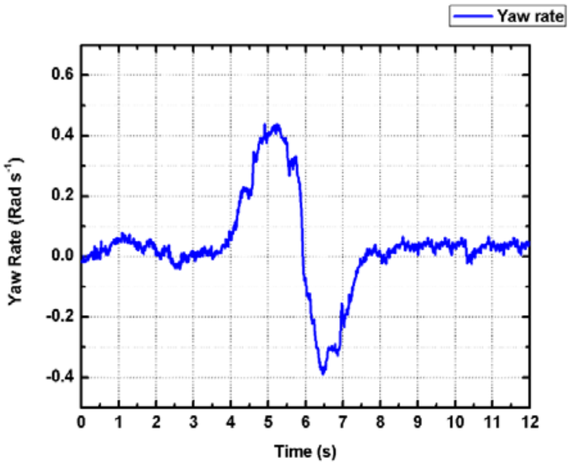

Figure 13. Yaw rate against the time.

Table 10. Maximum and minimum Yaw rate of the EPW

Max and Min Yaw Rate	EPWe
Maximum (Rad/s)	0.44
Minimum (Rad/s)	-0.39

4.1.2. Participant = Female Student

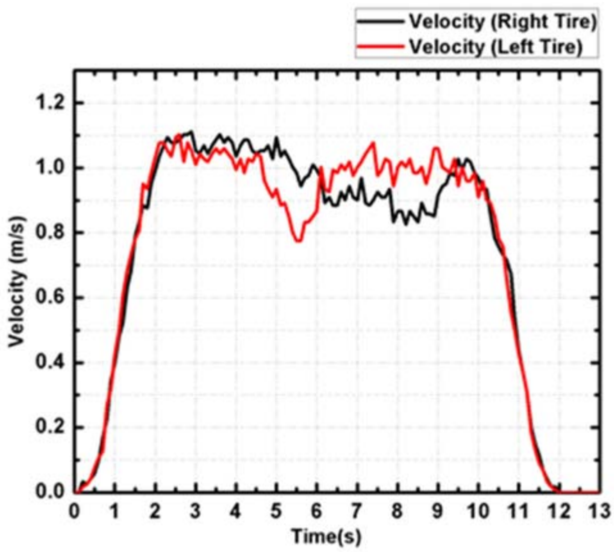

Figure 14. Velocity of right and left tires against time during the experiment for female student.

Table 11. The maximum and minimum velocity of right and left tires of EPW for female student.

Max and Min Velocity	Right Tire	Left Tire
Maximum (ms^{-1})	1.10	1.11
Minimum (ms^{-1})	0.03	0.02

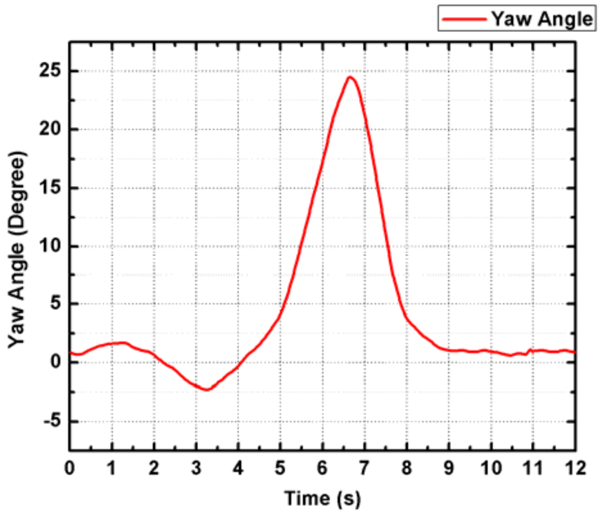

Figure 15. The changes in Yaw angle against time for female participant.

Table 12. Maximum and minimum Yaw angle of EPW.

Max and Min Yaw Angle	EPWe
Maximum (Degree)	24.47
Minimum (Degree)	-2.31

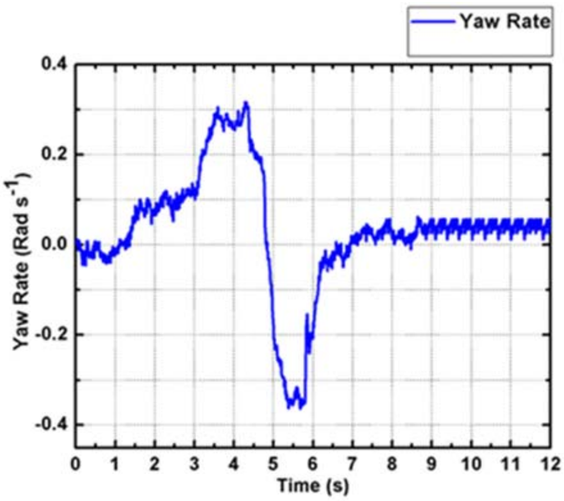

Figure 16. Yaw rate against the time for female participant.

Table 13. Maximum and minimum Yaw rate of the EPW.

Max and Min Yaw Rate	EPWe
Maximum (Rad/s)	0.32
Minimum (Rad/s)	-0.36

4.2. Second Speed = 1 ms^{-1}.
The experiment is conducted for the second speed with the speed of 1 ms^{-1}. The condition for the experimental set up and the procedure kept in constant.

4.2.1. Male Student

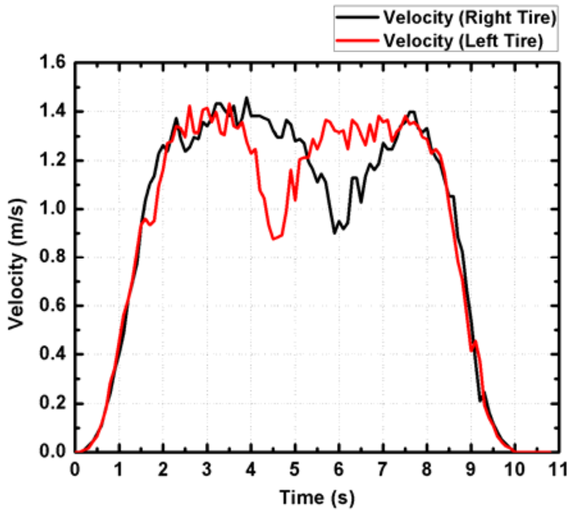

Figure 17. Velocity of right and left tires against time during the experiment for male student of second speed.

Table 14. The maximum and minimum velocity of right and left tires of EPW for male student.

Max and Min Velocity	Right Tire	Left Tire
Maximum (ms^{-1})	1.46	1.43
Minimum (ms^{-1})	0.03	0.02

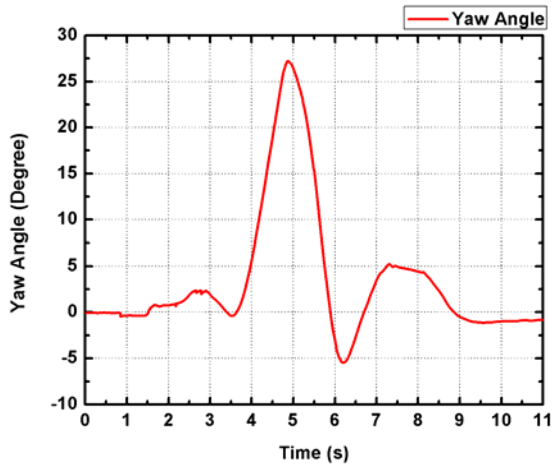

Figure 18. The changes in Yaw angle against time for male student.

Table 15. Maximum and minimum Yaw angle of EPW

Max and Min Yaw Angle	EPWe
Maximum (Degree)	27.21
Minimum (Degree)	-5.47

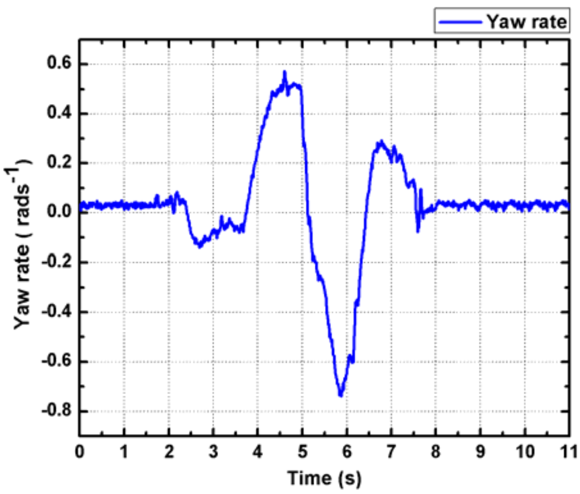

Figure 19. Yaw rate against the time.

Table 16. Maximum and minimum Yaw rate of the EPW.

Max and Min Yaw Rate	EPWe
Maximum (Rad/s)	0.57
Minimum (Rad/s)	-0.74

4.2.2. Female Student

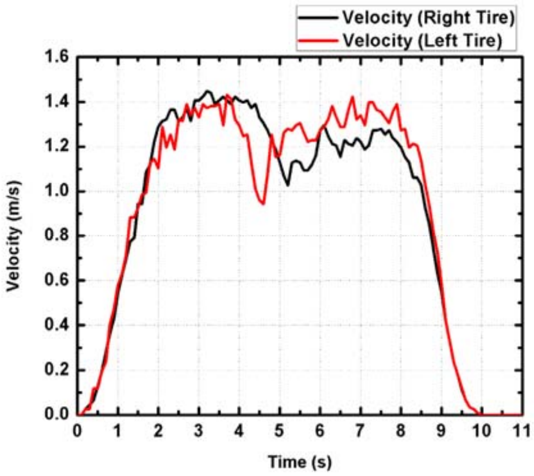

Figure 20. Velocity of right and left tires against time during the experiment for female student of second speed.

Table 17. The maximum and minimum velocity of right and left tires of EPW for female student.

Max and Min Velocity	Right Tire	Left Tire
Maximum (ms^{-1})	1.44	1.44
Minimum (ms^{-1})	0.03	0.03

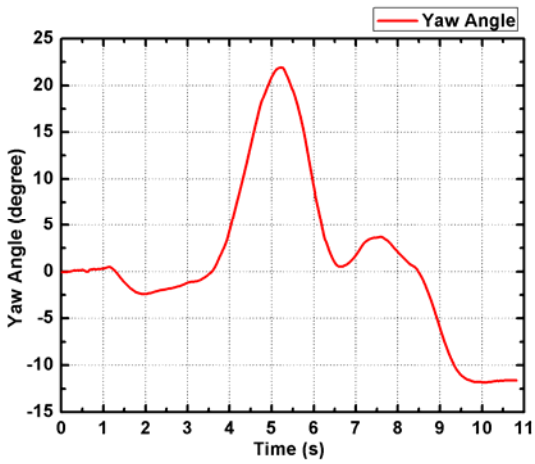

Figure 21. The changes in Yaw angle against time for female participant.

Table 18. Maximum and minimum Yaw angle of EPW.

Max and Min Yaw Angle	EPWe
Maximum (Degree)	21.90
Minimum (Degree)	-11.82

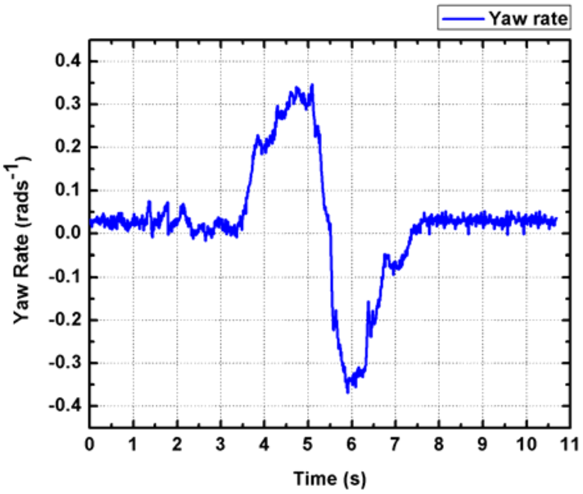

Figure 22. Yaw rate against the time for female participant.

Table 19. Maximum and minimum Yaw rate of the EPW.

Max and Min Yaw Rate	EPWe
Maximum (Rad/s)	0.35
Minimum (Rad/s)	-0.36

5. Discussion

This section will elaborate on the results that collected from the experiments. The result is based on the average on each trials that have been conducted. Each student given five trials to maneuver the EPW.

Base on the results gained, the trend of the graph is significantly almost the same. Base on the result from male and female student with the speed of 0.8 ms^{-1}, the time taken to finish each trial is almost 12 seconds. For the male student, the highest velocity during the obstacle avoidance is 1.16 ms^{-1} for the right tire. The Yaw angle or the turning angle of the male student during mitigating the obstacle is 24.49 degree. While the female students record the highest velocity during the obstacle avoidance for the right tire is 1.10 ms^{-1}. The angle taken to avoid the obstacle is 24.47 degree.

For the second speed, the time taken for each of the students to finish the trials is shorter compared to the first speed with almost 10 seconds. The speed of the right tire that collected for this experiment is also higher from the first speed. The highest right tire speed collected during the avoidance is 1.46 ms^{-1} for male student. The angle also slightly changes for this second speed by which 27.21 degree for the male student. Female student also recorded higher velocity reading compared to first speed with 1.44 ms^{-1} with the turning slightly decrease due to safety concern with 21.90 degree due to drastically change of EPW direction during the obstacle avoidance.

Based on the results collected, the students more prefer to maneuver the EPW with the speed of 0.8 ms^{-1} which is more convenient rather than the second speed. The speed with 1.0 ms^{-1} is more hardly to control during the obstacle avoidance due to the drastic change in direction during the obstacle avoidance.

6. Conclusion

From this experiment, the maneuvering of EPW from male and female students of Universiti Malaysia Pahang does not affect the trend of speed during the obstacle avoidance.

Based on the results taken, the student is preferring more in maneuvering the EPW with the first speed due to this speed is more convenient to be control from the second speed. Thus the first speed could be used as the reference speed for the autonomous wheelchair and this speed considered as the speed of walking. The comfort level for the first speed is more suitable to ride rather than the second speed.

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