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Wheelchair Speed Adjustment Based on Fuzzy Logic Controller for User Comfort

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Abstract— *The smart wheelchair has a dc motor as its driving force so that the wheelchair can move automatically. Wheelchairs are used to facilitate the mobility of patients and people with disabilities. The level of comfort of a wheelchair is a significant concern in the design of intelligent wheelchair speeds. Wheelchair speed is intelligently controlled using fuzzy logic controls with two inputs, which are displacement speed and error, and output in the form of PWM (Pulse Width Modulation) values. Fuzzy logic control input data is obtained from rotary encoder sensor readings, and PWM values are used to drive dc motors through motor drivers. Smart wheelchair walking following a predetermined trajectory. Test results from the zero point into the bedroom with a load of 43 kg, using a controller, obtained an acceleration value of 5.010593 cm / s^2 and deceleration -1.61225 cm / s^2. In contrast, testing without a controller yields an acceleration and deceleration with values of 12.71532 cm/s^2 and -2.1559 cm/s^2, respectively. Based on the controller's test results, the resulting acceleration and deceleration values are smaller so that user comfort can be more awake. The level of comfort of a wheelchair was assessed using a questionnaire. The average response of thirty respondents stated that setting the wheelchair's speed from zero to the sleeping room was comfortable.*

Keywords— Smart Wheelchair, Fuzzy Logic Controller, Speed, Displacement Errors

1. Introduction

Persons with disabilities and hospital patients use wheelchairs to facilitate activities. Generally, wheelchairs are operated manually, so they need the help of others or independently in moving them. Wheelchairs are growing so that they can make it easier for users. Previous research has made an intelligent wheel chair using head movement with On-Off control and the New Visual Joystick method to move the wheelchair [1]. The electric wheelchair is controlled by fuzzy logic, and its movement is used by voice control with a voice recognition module. Tests carried out using the voice recognition module have a success percentage of 82.85%. The wheelchair speed control method that is commonly used is PID control, based on subject intensity using bioelectrical impedance on horizontal, uphill, and flat tracks with 3-speed variables. In addition, intelligent wheelchair arrangements have been made using fuzzy logic control methods to avoid obstacles [2] and designs on uphill tracks [3] and derivatives with inputs in the form of initial velocity error values and delta error, maintaining wheelchair comfort by adjusting the speed when the track goes up the same as the speed when the way is flat.

The intelligent wheelchair is designed to be able to move along a predetermined trajectory using fuzzy logic control. Fuzzy logic control has two inputs: speed and displacement error and output in the form of PWM (Pulse Width Modulation) values. The movement of the dc motor is regulated using a motor driver by providing a PWM value to the dc motor. The reason for choosing fuzzy control as a controller is because there is no need to look for a mathematical model of a system. However, the fuzzy controller is still effective because it has a stable system response. In addition, the fuzzy logic controller can still work with the reduction of some rules, or if there is a small error in the programming, without any significant changes [4].

2. Research Methodology

This research was implemented in several stages, namely the hardware design stage, determining the trajectory plan, and designing a control method using the Sugeno method of fuzzy logic.

2.1 Hardware Design

The hardware used is a microcontroller, encoder sensor, motor driver, and dc motor. The wheelchair speed is detected using a rotary encoder sensor in pulses translated by the microprocessor into the wheelchair speed. The wheelchair speed is processed into momentum, and the speed error is used as input for fuzzy control. The controller will process the input data. The results of the control processing in the form of a PWM signal are used as input for the motor driver to drive the dc motor according to the output value of the microcontroller. A dc motor is used as power to move the wheels of the wheelchair. The wheel movement of the wheelchair is read by the encoder sensor and sent back to the microcontroller. This process is continuous and will maintain the desired wheelchair speed. The block diagram of the proposed hardware system can be seen in Figure 1.

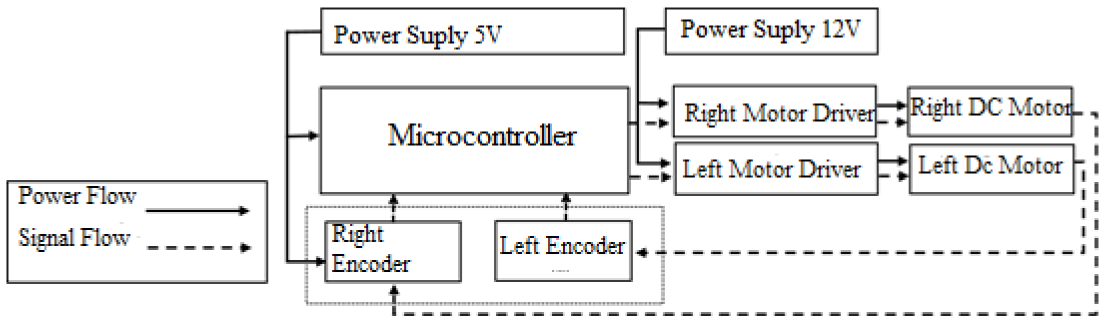

Fig. 1. *Hardware System Block Diagram*

2.2 Wheelchair Line Design

In this paper, the wheelchair is tested to move according to the specified trajectory. Figure 2 is an intelligent wheelchair trajectory. The smart wheelchair will run according to the instructions given.

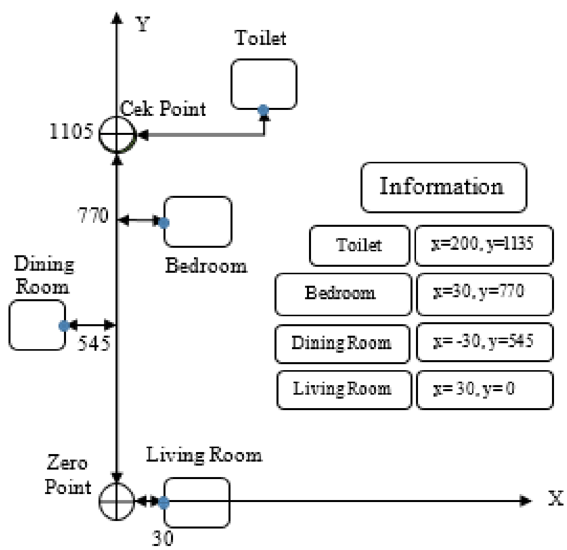

Fig. 2.*Speed Input Membership Function*

Figure 3 is a membership function of the speed value, where SVS means Speed Very Slow, SS means Speed Slow, SMF means Speed Medium Fast, SF means Speed Fast, and SVF means Speed Very Fast.

2.3 Sugeno Fuzzy Control Design

Fuzzy has two inputs, namely wheelchair speed and wheelchair displacement error, and output in the form of PWM. These values are divided into five fuzzy membership functions, as shown in Figure 3, Figure 4, and Figure 5. The speed input range has a value of 0 cm/s to 49.82 cm/s, and the displacement error has a value range of 0 cm – 1,105 cm.

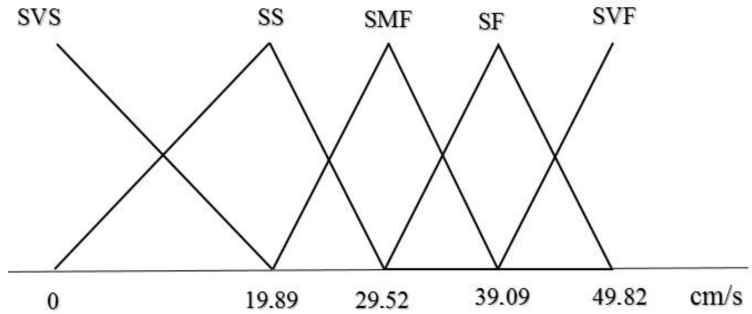

Fig. 3. *Intelligent Wheelchair Track Plan*

Figure 3 is a membership function of the speed value, where SVS means Speed Very Slow, SS means Speed Slow, SMF means Speed Medium Fast, SF means Speed Fast, and SVF means Speed Very Fast.

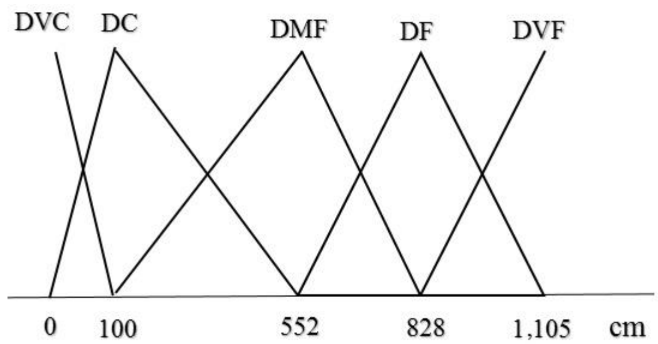

Fig. 4. *Displacement Error of Input Membership Function*

The membership function of the displacement error value is shown in Figure 4; namely, DVC means Displacement error Very Close, DC means Displacement error Close, DMF means Displacement error Medium Far, DF means Displacement error Far, and DVF means Displacement error Very Far.

The process after designing the form and number of membership functions is to develop a rule base, which serves to determine the attitude of the controller towards a situation from the two inputs [5-7]. The design of the rule base is shown in Table 1.

Table 1: Design of Rule Base

Error P / **V**	**DVC**	**DC**	**DMF**	**DF**	**DVF**
SVS	PVS	PVS	PVS	PVS	PVS
SS	PVS	PS	PM	PB	PVB
SMF	PS	PM	PB	PB	PVB
SF	PS	PM	PM	PB	PB
SVF	PM	PM	PB	PB	PB

Membership function for fuzzy control output used singleton membership function [8]. Singleton is a fundamental value used to produce the outcome of the fuzzy controller in the form of PWM. There are two outputs, namely the left PWM and the right PWM, which have a PWM value range of 0 – 999. Figures 5(a) and 5(b) show the singleton used in this study. The left PWM value ranges from 185 to 545, while the right PWM value has a range of 170 to 595. PVS means Very Small PWM, PS means Small PWM, PM means Medium PWM, PB means Big PWM, and PVB means Very Big PWM

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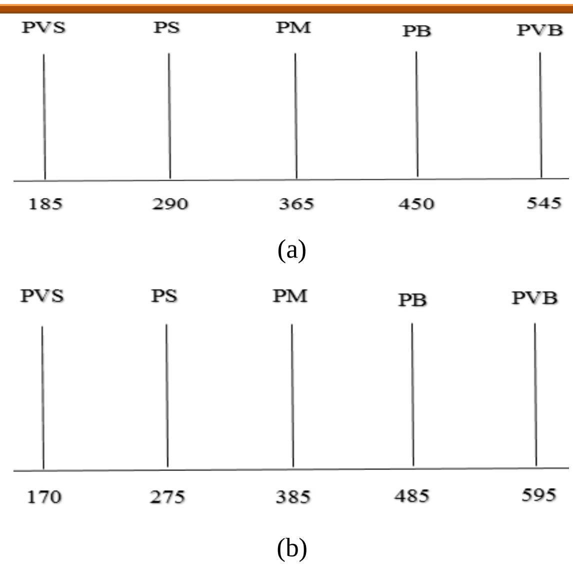

Fig. 5. *Singleton PWM (a) Left , (b) Right*

The defuzzification process uses the weighted-average (WA) method by adding each weight to the output value, then dividing it by the total weight using Equation 1 [9-11].

$$WA = \frac{W1*VSmall+W2*VSmall ...+W25*Big}{(W1+W2 ...+W25)} \quad (1)$$

3. Result and Discussion

In this section some testing are performed to verify the performance of our design.

3.1 Encoder Sensor Testing

The encoder reading data in the form of pulse units are processed using Equation 2

$$RPS = encoder\ value\ x\ \frac{1}{one\ round\ pulse\ x\ Ts} \quad (2)$$

RPS denotes the round of encoder during sampling period. The encoder value is obtained from the encoder sensor reading value. The resolution value of the encoder/pulse one revolution is 1920 pulses in one wheel rotation. Time sampling is the sampling time of data performed by the microcontroller every 40ms. RPS data will be processed into angular velocity data using Equation 3.

$$\omega = 2\pi\ RPS \quad (3)$$

The angular velocity data will be calibrated using a tachometer. The calibrated angular velocity data is converted to linear velocity (v) using equation 4.

$$v = \omega r \quad (4)$$

Table 2 is a test of the encoder sensor readings compared to measurements using a tachometer. To obtain the error value (%), then use Equation 5

$$Error\ \% = \frac{tachometer\ value - encoder\ value}{tachometer\ value} \quad (5)$$

The tachometer value is the value of the tachometer reading in cm/s, and the encoder value is the encoder sensor reading data converted into cm/s units. The most significant error value is 4.167%, with the encoder sensor reading 4.6 cm/s and the tachometer reading 4.8 cm/s. The overall error value can be seen in Table 2.

Table 2: Sensor Encoder Test

Encoder (cm/s)	Tachometer (cm/s)	*Error* (%)
4,6	4,8	4,166666667
7	7,2	2,777777778
9,1	9,4	3,191489362
10,6	10,9	2,752293578
12,1	12,4	2,419354839
13,3	13,5	1,481481481
15,1	15,4	1,948051948
16,5	16,9	2,366863905

3.2 Controller Test

The data obtained from the test in the form of speed in cm/s will be converted into acceleration data in cm/s2. Based on the test, the smaller the acceleration value, the better the wheelchair comfort.

- Zero-point to the dining rum (545cm)

Based on Figure 6, the test without a controller takes 15.93 s from zero to the dining room, while the test using a controller takes 57.761s.The average acceleration value when testing without a controller at 0s – 1.003 s is 31.81456 cm/s2, and the moderate deceleration at 11.8 s – 15.93 s is -7.89687 cm/s^2. Testing using the controller, the average acceleration value at 0 s – 7.906 s is 4.03238 cm/s^2, and the moderate deceleration at 55.578 s – 57.761s is -5.13827 cm/s^2. The acceleration comparison graph can be seen in Figure 7.

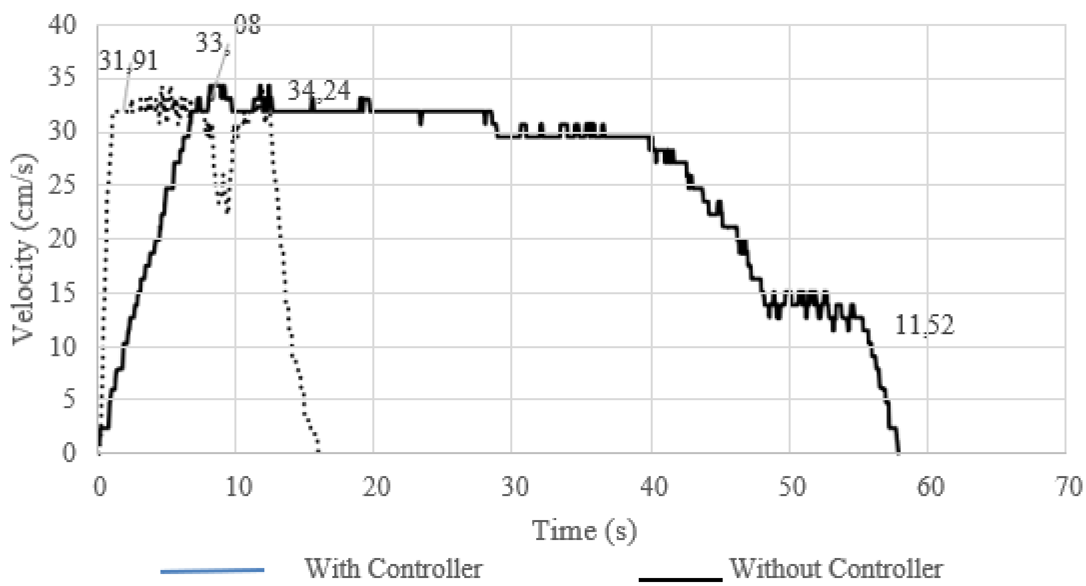

Fig. 6. *Comparison of Speed With and Without Controller with a distance variation of 545 cm and load of 43 kg travel time*

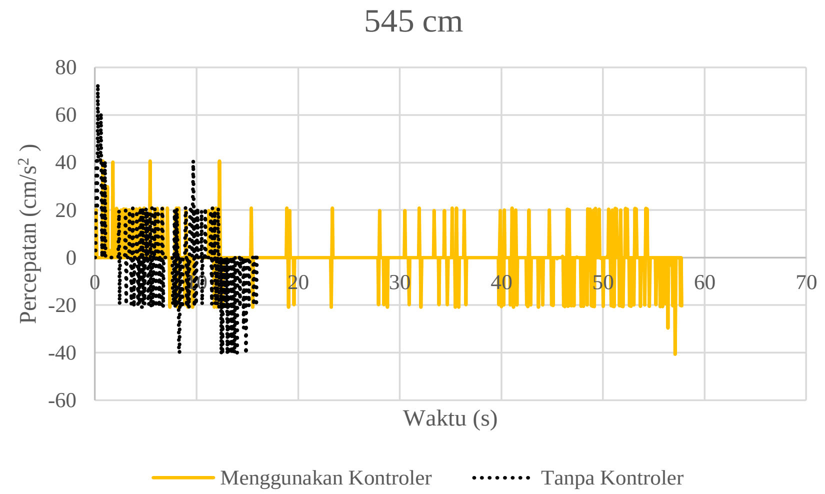

Fig. 7. *Comparison of Acceleration with and without Controller with a distance variation of 545 cm for travel time*

- Zero-point to The Bedroom (770cm)

Figure 8 is a comparison graph of speed without a controller and using a 770cm distance variation controller with a load of 43kg against time. Testing without a controller takes 25.37s to reach the destination, while testing using a controller takes 76.995 s.

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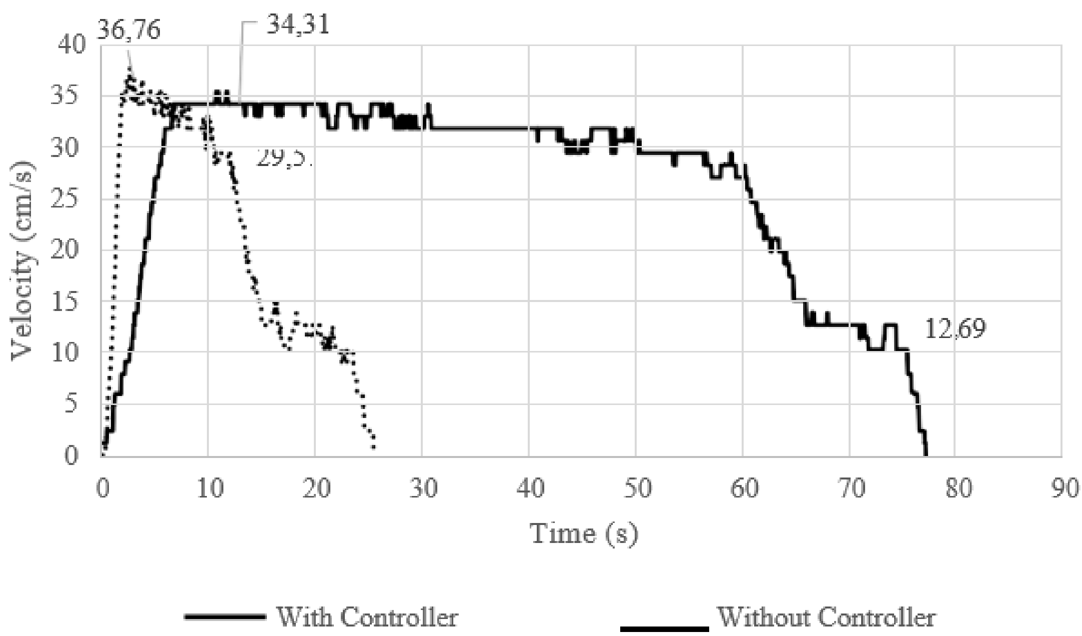

Fig. 8. *Comparison of Speed Variation with and without a controller for a distanve of 770sm and load of 43kg*

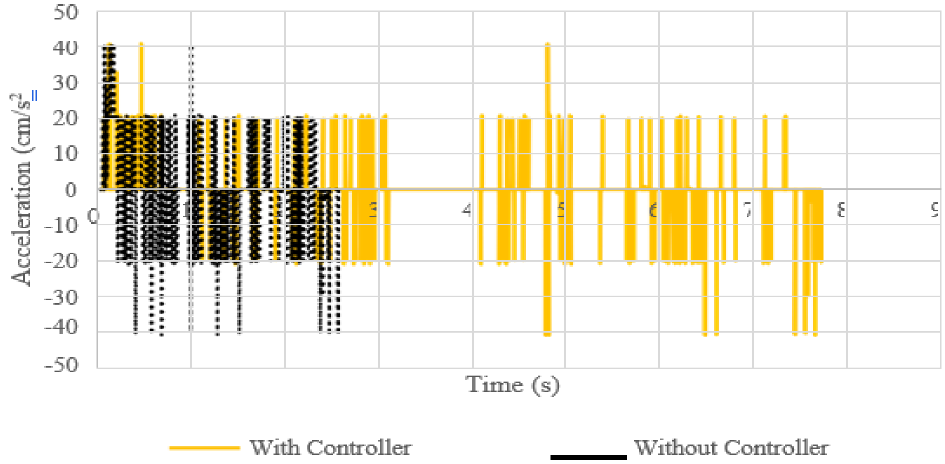

Fig. 9. *Comparison of Acceleration Variation with and without a controller for a distanve of 770sm and load of 43kg*

The acceleration comparison graph is shown in Figure 9. Based on the speed data from the test, the average acceleration value during the test without a controller at 0s – 2.891 s is 12.71532 cm/s^2, and the average deceleration at a time of 11.741 s – 25.37 s is -2.1559 cm/s^2. Tests using a controller, the average acceleration value at time 0 s – 6.608 s is 5.010593 cm/s^2, and the average deceleration at time 60.239 s – 76.995 s is -1.61225 cm/s^2.

- Zero point to check point (1,105cm)

Tests carried out from the zero point to the check point when testing without a controller took 27.789s, while testing using a controller took 98.648 s as shown in Figure 10.

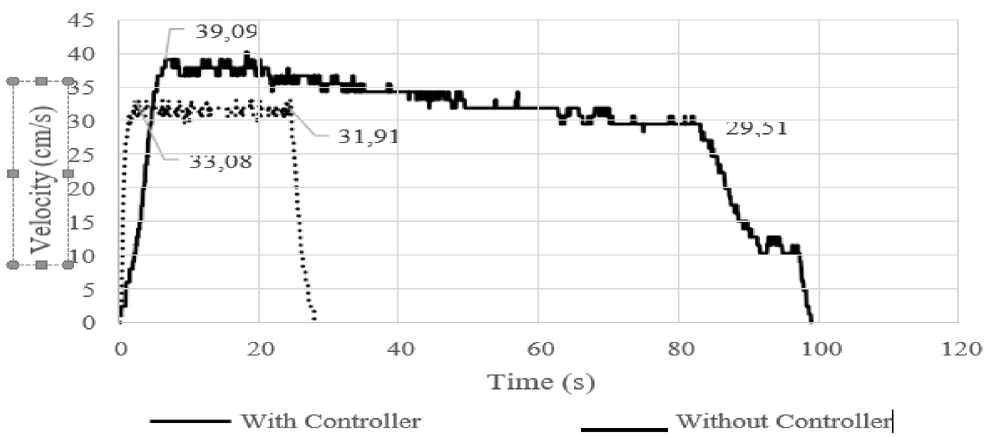

Fig. 10. *Testing of speed variation for the distance of 1,105 cm with and without controller for a load of 43kg*

The average acceleration value when testing without a controller at 0 s–2.183 s is 15.54511 cm/s^2, and the average deceleration at 24.308 s – 27.789 s is -9.49702 cm/s^2, while the acceleration value when testing using a controller is the average time of 0 s – 6.49 s is 6.09556 cm/s^2 and the average deceleration at the time of 82.836 s – 98.648 s is -1.95898 cm/s^2. Figure 11 is a comparison graph of acceleration.

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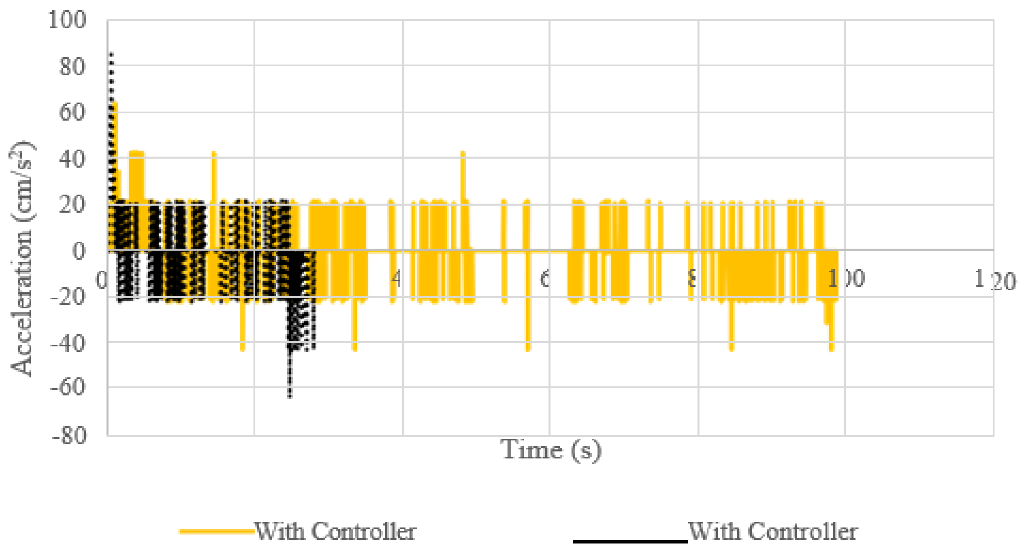

Fig. 11. *Comparison of acceleration with and without controller for distance variation of 1,105cm with a load of 43kg*

3.3 Comfort Testing

Comfort testing is done by testing 30 respondents. Each respondent will fill out a questionnaire. The questionnaire as data supports that the fuzzy output is appropriate. Each respondent will assess the speed setting at the start and braking on a scale of 1-5. Strongly disagree (STS)=1, disagree (TS)=2, neutral (N)=3, Agree (S)=4, and strongly agree (SS)=5. The average data recap of responses from 30 respondents can be seen in Table 3. Based on Table 3, it can be seen that fuzzy logic control can maintain user comfort compared to without a controller.

Table 3: Average Response of 30 Respondents

No	Movement Distance	Average response			
		Without Contrller		*With Controller*	
		Start	*Braking*	*Start*	*Braking*
1.	545 cm	2,46	2,06	4,66	4,6
2.	770 cm	2,36	1,9	4,66	4,5
3.	1.105 cm	2,3	2,2	4,5	4,4

Table 4: Recapitulation of Test with A Load of 43kg.

Movement Distance (cm)	Acceleration (cm/s^2)		Average responses	
	Start	Braking	Start	Braking
545	4,03238	-5,13827	5	4
770	5,010593	-1,61225	5	5
1,105	6.09556	-1,95898	4	5

Table 4 summarizes the acceleration test data with a load of 43 kg with variations in the displacement distance of 545 cm, 770 cm, and 1,105 cm. Based on Table 4, the test uses fuzzy logic control when the variation of the displacement distance of 770 cm is very comfortable with an acceleration value of 5.010593 cm/s^2 and a deceleration of -1.61225 cm/s^2.

4. Conclusion

Based on the tests carried out, it can be concluded that fuzzy logic control with Sugeno method can improve the level of user comfort when the displacement distance is 770 cm with an acceleration of 5.010593 cm/s^2 and a deceleration of -1.61225 cm/s^2. Moreover, questionnaire results that have been conducted state that the wheelchair speed setting has been comfortable.

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