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IoT-Based Smart Wheelchair System for Physically Impaired Person

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ABSTRACT

Disabled persons usually require an assistant to help them in their daily routines especially for their mobility. The limitation of being physically impaired affects the quality of life in executing their daily routine especially the ones with a wheelchair. Pushing a wheelchair has its own side effects for the user especially the person with hands and arms impairments. This paper aims to develop a smart wheelchair system integrated with home automation. With the advent of the Internet of Things (IoT), a smart wheelchair can be operated using voice command through the Google assistant Software Development Kit (SDK). The smart wheelchair system and the home automation of this study were powered by Raspberry Pi 3 B+ and NodeMCU, respectively. Voice input commands were processed by the Google assistant Artificial Intelligence Yourself (AIY) to steer the movement of wheelchair. Users were able to speak to Google to discover any information from the website. For the safety of the user, a streaming camera was added on the wheelchair. An improvement to the wheelchair system that was added on the wheelchair is its combination with the home automation to help the impaired person to control their home appliances through Blynk application. Observations on three voice tones (low, medium and high) of voice command show that the minimum voice intensity for this smart wheelchair system is 68.2 dB. Besides, the user is also required to produce a clear voice command to increase the system accuracy.

Keywords: *physical disabilities; Google assistant; voice command; smart wheelchair; IoT*

1. INTRODUCTION

People with a disability are the ones who are not able to do the major physical activities by themselves as they need special kind of support in their daily routines either doing the activity deals with other person or with an equipment. Some of them are born physically handicapped and others are caused by diseases that lead to hand and arm impairments. Department of Statistic Malaysia (DOSM) states that physically impaired person is the highest percentage with 35.2 % recorded in 2017 compared to other disabilities [1].

Most of older people in Malaysia commonly start to develop physical disabilities and functional limitations when they are in the range of older age [2]. These disabilities cause them to lose autonomy, feel isolated, and increase the burden in social life and rate of depression. The disabled people have to face many challenges in their lives, and they need to adapt to their disabilities. In 2017, World Health Organization (WHO) stated that 15 % of the world population has some form of disabilities and 2 to 4 % experience severe difficulties in functioning [4].

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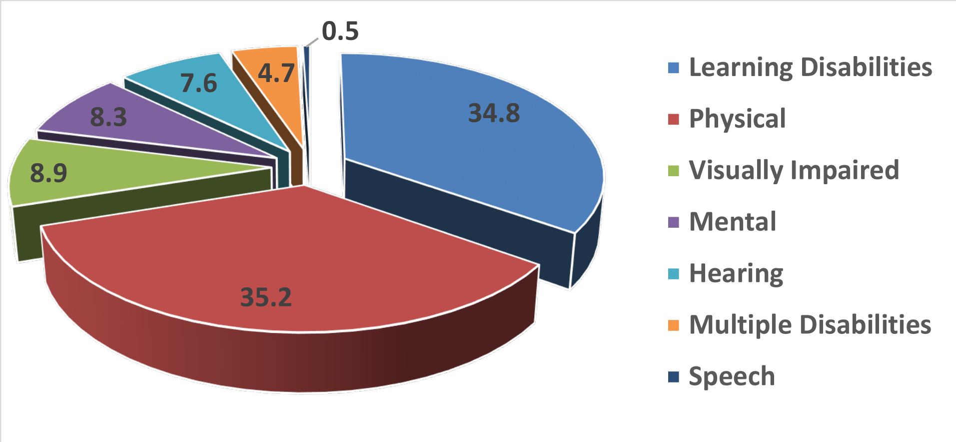

Figure 1: Statistic of Persons with Disabilities in Malaysia [1]

Pushing the wheelchair is not convenient for the elderly and aged user. The user would enhance the risk of substantial parts of their body to lose their function [5]. Most of the elderly persons would experience postural deformities that lead to negative impacts on their ability to control the pushing wheelchair such as spinal cord injury on the shoulder [6]. Other than that, pelvic deformities and upper limb are also the risks that the user would face. Due to the improvements in technology, this project aims to develop a smart wheelchair with the Google assistant platform for the operation. In addition to this, the smart home automation will also be developed using Blynk application as the additional features by taking the advantages of the new era of industrial revolution 4.0 to help the impaired persons to improve their quality of life at home, increase their life quality and facilitate their integration into the real world.

From previous studies, many researchers have proposed their project on the smart wheelchair. There is a number of methods using different techniques that have been proposed as a controller for the wheelchair movements as listed in Table 1. The techniques that have been proposed are brain computer interface (BCI)-controlled with the help of Electroencephalogram (EEG) [9], head pose estimation control [7], eye tracking-control [8] and speech/voice-control [11]–[15]. Focusing on speech/voice-controlled wheelchair system, three techniques that are commonly used for speech/voice-controlled wheelchair system are HTML and JavaScript implementation [10], voice recognition [11], [13]–[15] and convolutional neural network (CNN) [12]. For the speech/voice controlled-wheelchair, voice command is required to steer the wheelchair since voice is the natural way of people communication. Consequently, speech/voice-controlled wheelchair would help the physically disabled people with hand and arm impairments to control the wheelchair.

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Table 1: Smart Wheelchair with Different Techniques

Authors	Paper Title	Year	Technology
F.A. Kondori, S. Yousefi, L. Liu, and H. Li [7]	Head operated electric wheelchair	2014	Kinect, Range image
S. Shinde, S. Kumar, and P. Johr [8]	Eye Tracking Interface with Embedded System & IOT	2018	Eye coordination and Eye tracking
L. Yang, Y. Ge, W. Li, W. Rao, and W. Shen [9]	A home mobile healthcare system for wheelchair users	2014	Brain interface (BCI) with Electroencephalogram (EEG)
F. A. Kondori, S. Yousefi, L. Liu, and H. Li [7]	Head operated electric wheelchair	2014	Head pose estimation
A. Škraba, A. Koložvari, D. Kofjač, and R. Stojanović [10]	Prototype of speech controlled cloud based wheelchair platform for disabled persons	2015	Speech controlled with the HTML and JavaScript implementation
N. Aktar, I. Jaharr, and B. Lala [11]	Voice Recognition based Intelligent Wheelchair and GPS Tracking System	2019	Voice controlled using voice recognition and Global Positioning System (GPS) Tracking
M. S. I. Sharifuddin, S. Nordin, and A. M. Ali [12]	Voice Control Intelligent Wheelchair Movement Using CNNs	2019	Voice controlled using Convolutional Neural Network (CNN)

In this paper, the objective is to propose a novel speech/voice-controlled wheelchair system using the Google Assistant Artificial Intelligence Yourself (AIY) to steer the motion of smart wheelchair and home automation with the Blynk apps controller as the additional features.

2. METHODOLOGY

2.1. Overview of Smart Wheelchair System

Figure 2 shows the block diagram of the smart wheelchair system with the implementation of the real wheelchair position. However, in this project the system would be implemented on wheelchair prototype only. The smart wheelchair consists of a microphone, camera, microcontroller, motor driver, DC motor and output speaker. The microphone works as the input voice command from the user that converts the voice into an electrical signal and digitises the voice to Raspberry Pi 3 B+. In order to use the smart wheelchair, the voice command from the user must match the stored command to execute the output from the microcontroller. The voice command is processed by Google assistant that works as the artificial intelligence cloud. Google assistant is the platform for the user to have conversational interactions to ask any information from the Google service and all of the information is collected from Wikipedia.

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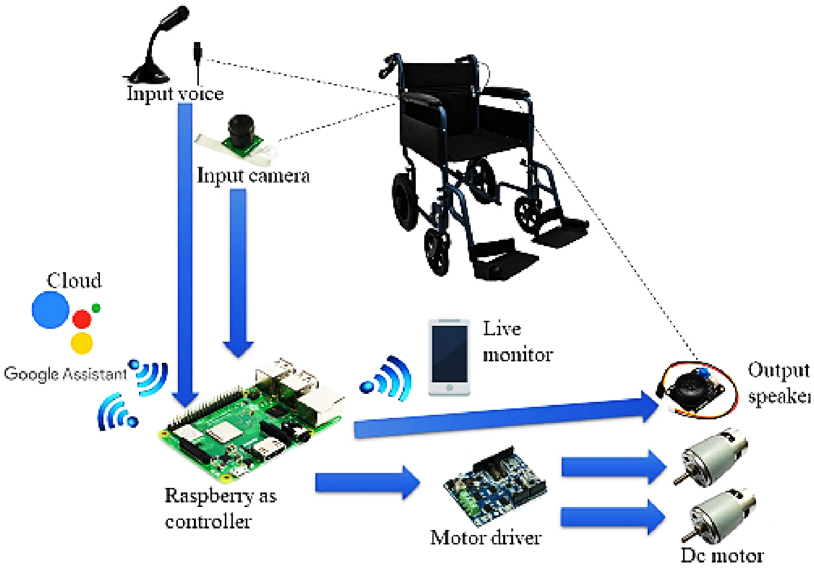

Figure 2: Block diagram of smart wheelchair

The motor driver is attached to the microcontroller with two DC motors applied on the motor driver. When the input voice matched with the stored command, the microcontroller executes the output by running the DC motor for the wheelchair movement. The rotation of the DC motor is based on the received voice command for five basic movements of forward, backward, turn left, turn right and stop. Output speaker is attached to give the feedback from Google service to the user. A mobile phone is used to monitor the live streaming from the wheelchair so that the current location can be traced by the care takers.

Figure 3 presents the block diagram of the home automation as the additional features on the smart wheelchair. This system is controlled by NodeMcu ESP8266 as its microcontroller. The input from the user is obtained from the Blynk apps which is installed on the smartphone. NodeMCU is connected to the relay to control the current flow from the source, 240 V. The output for the system is the appliances connected to the relay. Relay condition occurs due to the switch control in the Blynk apps.

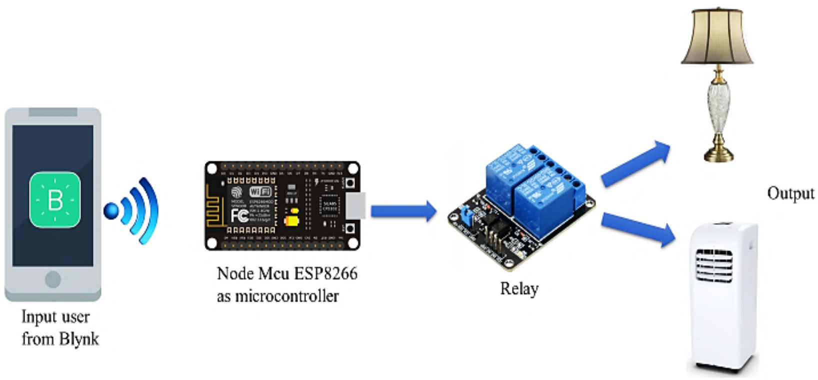

Figure 3: Block diagram of home automation

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2.2. *Voice Command Verification using Google Assistant*

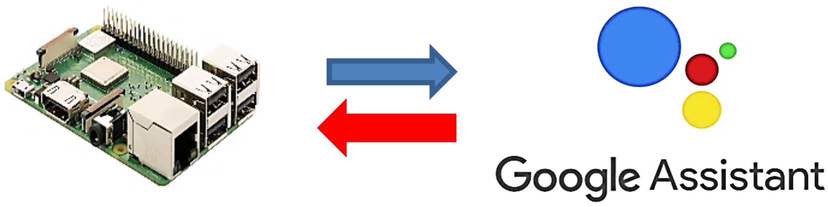

Figure 4: Two ways communication between microcontroller and cloud

Figure 4 shows the connection concept between the microcontroller with the cloud. Google assistant works as the decision-maker and processes any voice input from the user before Raspberry pi 3 B+ executes the output. Keyword "OK Google" is the key to activate the Google assistant so that the cloud will start to recognise and process the voice input from the user. If the keyword "OK Google" is not detected, the Google assistant will not respond and the command cannot be processed.

Raspberry Pi 3 B+ must be authorised by the Google service before using the Google assistant platform. Google allows any user to customise any project with permission. After the project is created in the Google dashboard, Google provides *assistant.json* file for the user to link the account of the user to the Google assistant. In the *json* file, there are client id and project id required by the Google assistant to verify the connected account as shown in Figure 5.

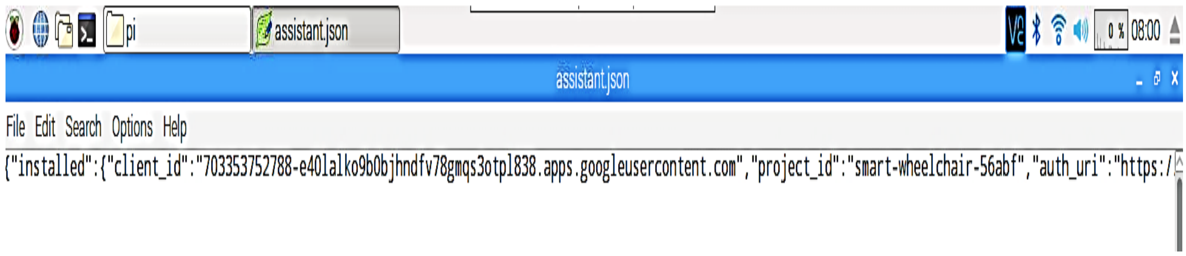

Figure 5: *assistant.json* file

Figure 6 presents the working principle for the developed smart wheelchair system. The system must be connected to the Wi-Fi connection as the Google service is the main process for voice command classification. There are five conditions of movement of this wheelchair which are moving backwards, moving forward, turn right, turn left and stop. Each movement has its own specific input command to steer the wheelchair. The system begins when the wheelchair is connected to the Wi-Fi connection. This system is always in the standby mode to receive the keyword from the user to activate the Google assistant. The Google assistant reacts whenever the keyword 'OK Google' is captured. Then, it will proceed to process the next command detected.

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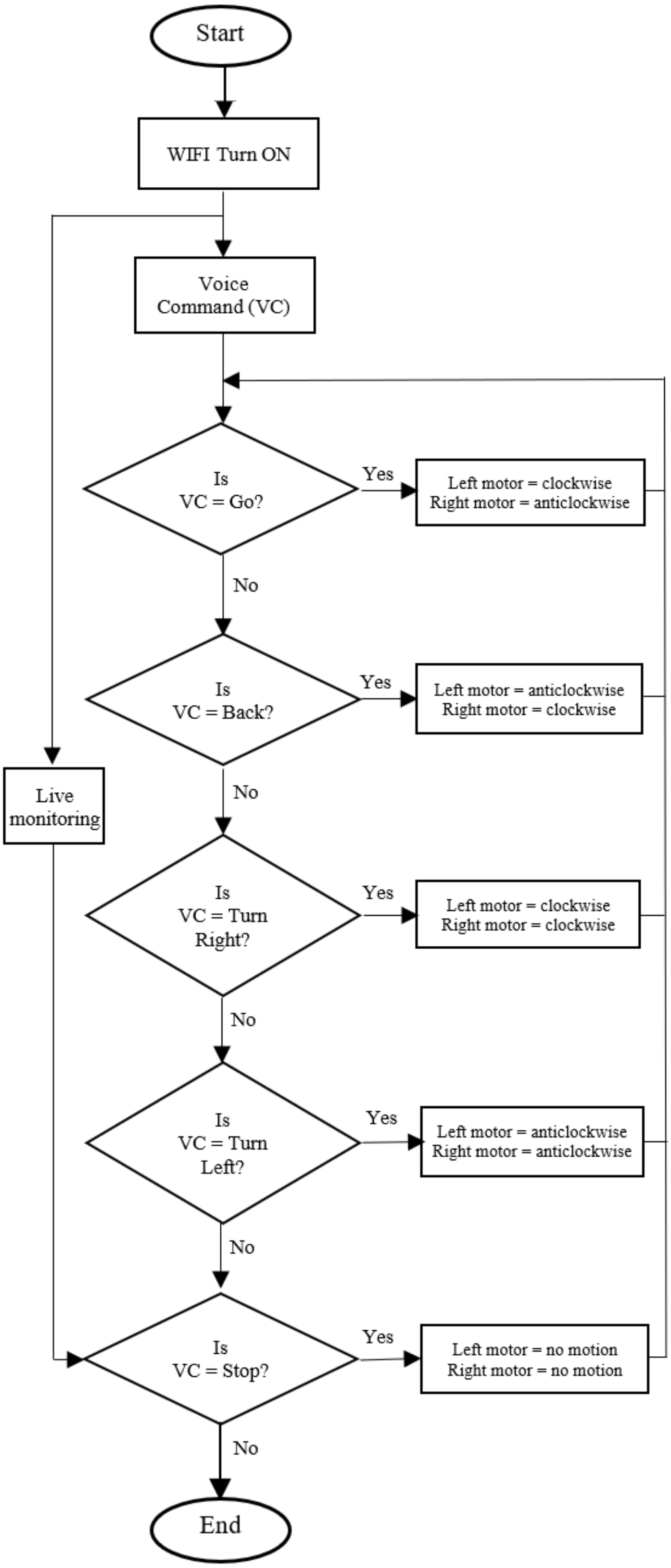

Figure 6: Flowchart for smart wheelchair

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The motion of the wheelchair is controlled by two DC motors. If the ‘go’ command is performed, the left motor will rotate in a clockwise direction and the right motor will rotate in an anticlockwise direction to move the wheelchair forward. For the ‘back’ command, the left motor will rotate anticlockwise and the right motor will rotate in a clockwise direction. Clockwise direction is generated for both motors when the command ‘turn right’ is delivered while the anticlockwise direction for both motors is produced when the command received is ‘turn left’. For the stop mode, both motors will not rotate and they will be steady in a fixed position. Table 2 summarises the motor rotation for the basic four motions of forward, backward, turn left and turn right. Each of the movement will be continuous until the next command is performed. For example, if the user has to turn right, the user can rotate at any angle until the user voices the command “stop” to the wheelchair. So, there is no fixed angle for the wheelchair to rotate and the user does not need to repeat the command.

Table 2: Summary of Motor conditions (Left and Right) for Four Basic Movements

Motion	Left Motor	Right Motor	Rotation
Forward	Low	High	Clockwise – Anticlockwise
Backwards	High	Low	Anticlockwise – Clockwise
Turn Left	High	High	Anticlockwise – Anticlockwise
Turn Right	Low	Low	Clockwise – Clockwise

To improve the safety of the user, a camera was added on the wheelchair so that the caretakers can monitor and stream the impaired person regularly. It can be monitored through the mobile device. The live monitoring from the wheelchair always works as long as the wheelchair is in standby mode.

Figure 7 shows the flowchart for the home automation system. It starts by logging in the Blynk apps with Wi-Fi connection required to activate the apps. After the Blynk apps is turned ON, the apps will update the current condition from the appliances. Then, the user decides to control the appliances whether to ON or OFF the appliances. The connection between relay and microcontroller helps to control the current flow.

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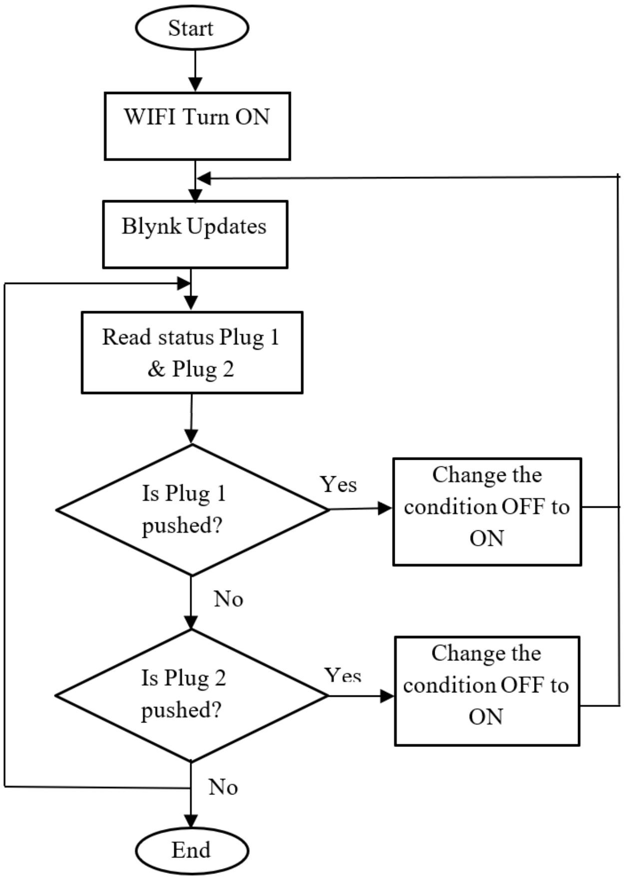

Figure 7: Flowchart for home automation

3. RESULTS AND DISCUSSIONS

Figure 8 shows the developed prototype for the smart wheelchair. The material used to frame the body parts is PVC (polyvinyl chloride) and the fabric seat for the wheelchair. The prototype is attached with a webcam camera and mobile device to control the home automation. The dimension of the prototype is 50 cm × 60 cm × 84 cm. The microphone is located on the right-hand side of the user while the camera is placed on the left-hand side. In this paper, only the prototype of the wheelchair is developed to prove the system functionality to be implemented in real life. The focus of this study is to implement the speech/voice-controlled controller system integrated with home automation. This system could be implemented to any existing real manual wheelchair. The load that could be sustained by this prototype wheelchair is only 5 kg. However, the load that can be sustained by the real wheelchair system depends on the maximum load of a manual wheelchair.

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Figure 8: Prototype of the smart wheelchair

3.1. Result for Google Assistant AIY Voice-Controlled Wheelchair System

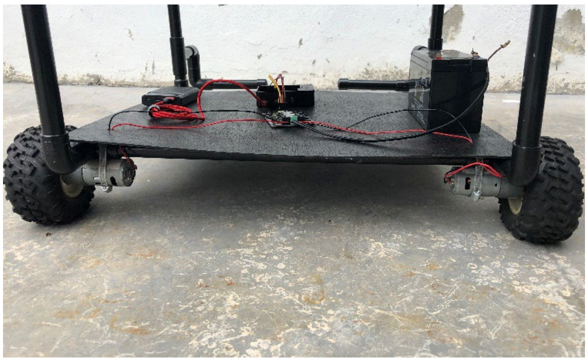

Figure 9: Two DC motors attached to the wheels

The wheelchair system was tested in two different environments which are inside a house and outside of the house. The inside house test was performed at a double story house while the outdoor test was performed at an open area of UiTM university. More than 30 voice samples have been tested and the sample voices were classified into three groups of voice tone according to the voice intensity (Low, Medium and High). The purpose of doing this is to verify the performance of the smart wheelchair with different tones of voice inputs. The range of voice intensity for the three voice tones was 48.2 dB to 67.2 dB for low voice tone, 68.2 dB to 77 dB for medium voice tone and 72.8 dB to 84.4 dB for high voice tone (Note that the standard range of noise inside a house environment is between 48.2 dB to 50.4 dB). The voice matching was verified by the Google assistant before the microcontroller executed the output. Figure 10 shows the condition where the Google assistant starts to process the next command after the keyword "OK Google" is performed. A voice sample is recorded as matched if the action performed by the wheelchair is matched with the voice command of the voice sample.

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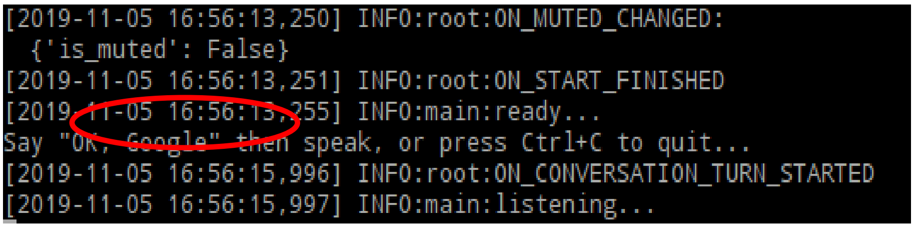

Figure 10: Google starts to listen to the next command

Table 3: The tested voices with voices matching result and analysis for indoor environment (10 samples for each voice tone)

No of Voice	Voice Intensity (dB)	Voice Matching	Percentage of matched voice	Average, $\bar{X}$	Standard Deviation, σ
Voice 1	49.8	×	20 %	**$\bar{X}$ of matched voice = 58.25** **$\bar{X}$ of unmatched voice = 54.95**	**σ of matched voice = 2.44** **σ of unmatched voice = 2.52**
Voice 2	52.3	✓			
Voice 3	49.4	×			
Voice 4	48.2	×			
Voice 5	49.0	×			
Voice 6	57.9	×			
Voice 7	67.2	×			
Voice 8	65.1	×			
Voice 9	53.0	×			
Voice 10	64.2	✓			
Voice 11	73.2	×	80 %	**$\bar{X}$ of matched voice = 73.30** **$\bar{X}$ of unmatched voice = 74.55**	**σ of matched voice = 1.49** **σ of unmatched voice = 1.16**
Voice 12	74.6	✓			
Voice 13	71.4	✓			
Voice 14	72.9	✓			
Voice 15	71.8	✓			
Voice 16	76.1	✓			
Voice 17	74.4	✓			
Voice 18	77.0	✓			
Voice 19	68.2	✓			
Voice 20	75.9	×			
Voice 21	79.9	✓	50%	**$\bar{X}$ of matched voice = 76.78** **$\bar{X}$ of unmatched voice = 81.76**	**σ of matched voice = 1.26** **σ of unmatched voice = 1.13**
Voice 22	82.3	×			
Voice 23	80.7	×			
Voice 24	77.2	✓			
Voice 25	72.8	✓			
Voice 26	84.4	×			
Voice 27	80.0	×			
Voice 28	81.4	×			
Voice 29	77.2	✓			
Voice 30	76.8	✓			

Low Medium High ✓ Matched × Unmatched

Table 3 shows the voice matching result and analysis for 30 voice samples which are categorised by low, medium and high voice tones. The voice intensity for each voice sample is also included in the table. The average voice intensity and the standard deviation for matched and unmatched voice sample are also determined for every voice tone group. The low voice tone shows that 2 out of 10 voice samples are detected thus providing 20% detection. The standard deviation for the matched and unmatched voices are recorded as 2.44 and 2.52

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respectively. This concludes that low tone voice samples cannot be detected by the system with the high value of standard deviation for both matched and unmatched voice. It indicates that the low voice will not allow the system to trace the command well.

For the medium tone voice (68.2 dB – 77 dB), the result shows the best voice matching compared to the low and high tones with 8 out of 10 samples have been matched with 80% of matched voice. The standard deviation for the matched and unmatched voices are recorded as 1.49 and 1.16 respectively with average voice intensity of 73.3 (matched) and 74.55 (unmatched). The voice intensity does not seem relevant for medium voice tone because of the lower value standard deviation of the unmatched voice and the matched standard deviation. Sometimes, the voice cannot be traced by the system unless the keyword is clearly spoken by the user.

For the high tone voice (77.2 dB – 84.4 dB), 5 out of 10 samples are matched with the command in the library with 50% of matched voice. The standard deviations of the matched and unmatched voice samples are recorded as 1.26 and 1.13 respectively which are lower than the medium voice tone. Although the standard deviation is lower than the standard deviation of medium voice tone, the percentage of the matched voice is still low. This indicates that the high tone voice is not suitable for wheelchair control because of the lower matching percentage than the medium voice tone.

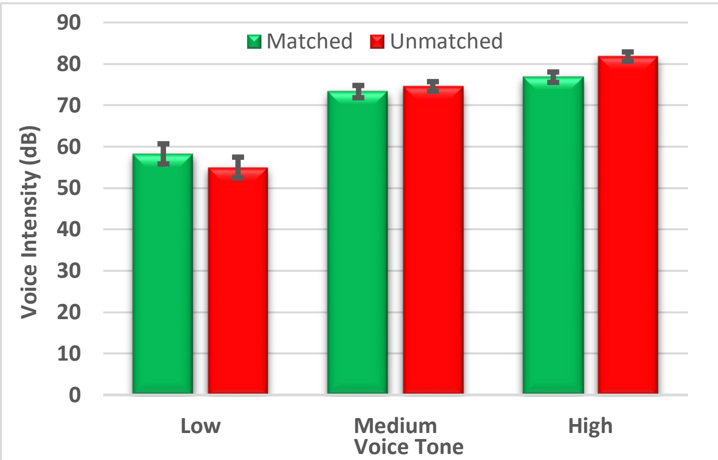

Figure 11: Average voice intensity of matched and unmatched for each voice category with error bar standard deviation during indoor environment test

Figure 11 shows the graph of average voice intensity with the error bar for the matched and unmatched voices for every voice tone. The average voice intensity of the matched voice with standard deviation for three voice tones for low, medium and high are recorded as 58.25 ± 2.44 dB, 73.30 ± 1.49 dB and 76.78 ± 1.26 dB respectively. The average voice intensity of the unmatched voice with standard deviation for low, medium and high are recorded as 54.95 ± 2.52 dB, 74.55 ± 1.16 dB and ± 1.13 dB respectively. Although the standard deviation for high tone is lower than medium tone, the percentage of the matched voice of 50% is much lower than the medium voice tone.

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As a summary, the medium voice tone is the most suitable tone for indoor wheelchair control due to its high percentage of the matched voice of 80%. Besides, the voice intensity analysis does not reflect the relationship between each voice tone and it is not relevant in decision making to determine the best voice tone for the voice-controlled wheelchair system. Therefore, the user is required to provide a clear voice command in medium voice tone to allow the system to work accurately. However, the standard deviation for medium and high voice tones is below 2 dB which is lower than the low voice tone that records a much higher standard deviation of greater than 2.4 dB.

The same measurement/test as in Table 3 has been conducted in outdoor environment which was performed at an open area of the university. This data proves that the smart wheelchair can be used outside of the house so that the impaired person can freely move. From the ten samples for the low voice tone, only 1 recorded matched voice which resulted in 10 % accuracy. For the medium voice tone, 7 out of 10 samples were recognised by the system. It shows that the system performance is good for the user to be used outside of the house. Medium tone recorded 70 % accuracy in the voice matching which is the highest compared to the low tone and high tone with only 10 % and 60 % accuracies respectively. High voice tone also seems to be suitable for outdoor environment application with 60 % accuracy. Figure 12 shows the graph of average voice intensity with error bar for the matched and unmatched voice for every voice tone in the outdoor environment. The average voice intensity of the matched voice with standard deviation for the three voice tones for low, medium and high are recorded as 56.30 ± 2.15 dB, 74.70 ± 1.52 dB and 77.50 ± 1.66 dB respectively. While the average voice intensity of the unmatched voice with standard deviation for low, medium and high are recorded as 53.20 ± 2.69 dB, 73.10 ± 1.33 dB and 81.05 ± 1.58 dB respectively. The standard deviation for low voice tone is higher than 2 dB, while the standard deviation for medium and high voice tones is below 2 dB.

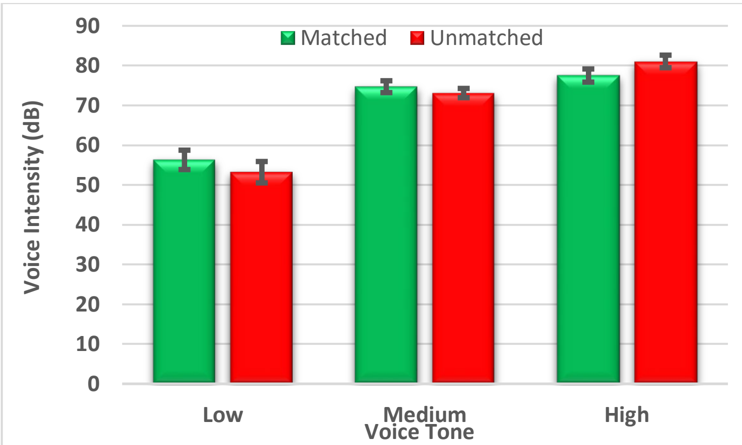

Figure 12: Average voice intensity of the matched/unmatched for each voice category with error bar standard deviation outside home environment

Since two voice tones of medium and high recorded the percentage accuracy of ≥ than 60% and standard deviation of < than 2 dB, the minimum voice intensity for the outdoor environment can be set to be equivalent to the minimum voice intensity for a medium tone which is 68.2 dB.

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3.2. Result for Webcam Streaming

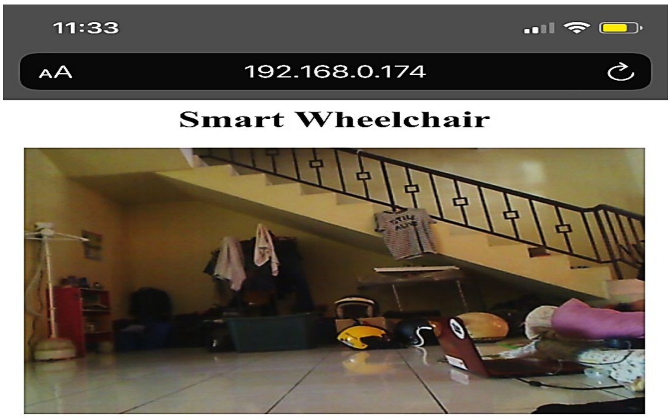

Figure 13: Webcam live monitoring from wheelchair

Figure 13 shows the stream monitoring from the mobile device. It could help the caretakers to monitor the impaired person regularly. The monitoring webcam is good for a child user when the child uses the wheelchair outside of the house. If something bad happens to the impaired person such as falling from the wheelchair, the caretakers will notice immediately, resulting in fast action. Thus, the condition of the impaired person would be more secure.

3.3. Result for Home Automation

For the home automation, there are two switches that a user can use to control the wheelchair which is by using Blynk Apps. The real-time status of the appliances displayed in the Blynk allows the user to trace the status of the appliances from time to time and control the home appliance. This project was successfully implemented since the user was able to control the home appliances by using Blynk apps on a smartphone. This method would really help the disabled person to monitor the condition of the house appliances without any human power. The disabled person does not need to get up from the wheelchair to turn ON/OFF the house appliances.

Figure 14(a) shows general home automation setup that includes home appliances, NodeMcu ESP8266 and Blynks app. Figure 14(b) to (d) show the real-time status of home appliances compared with the appliance status in Blynk apps. Three conditions have been observed to evaluate the effectiveness of the home automation system. In the first condition in Figure 14(b), the light is in ON condition for both real appliance devices and Blynk apps, and the air-conditioner is in OFF condition for both real appliance and Blynk apps. In the second condition in Figure 14 (c), the light is in OFF condition for both real appliance device and Blynk apps, and the air-conditioner is in ON condition for both real appliance and Blynk apps. In the third condition in Figure 14 (d), the light is in ON condition for both real appliance devices and Blynk apps, and the air-conditioner is in ON condition for both real appliance and Blynk apps. These three conditions prove that the system of the home automation works properly when it is controlled via Blynk apps by the user.

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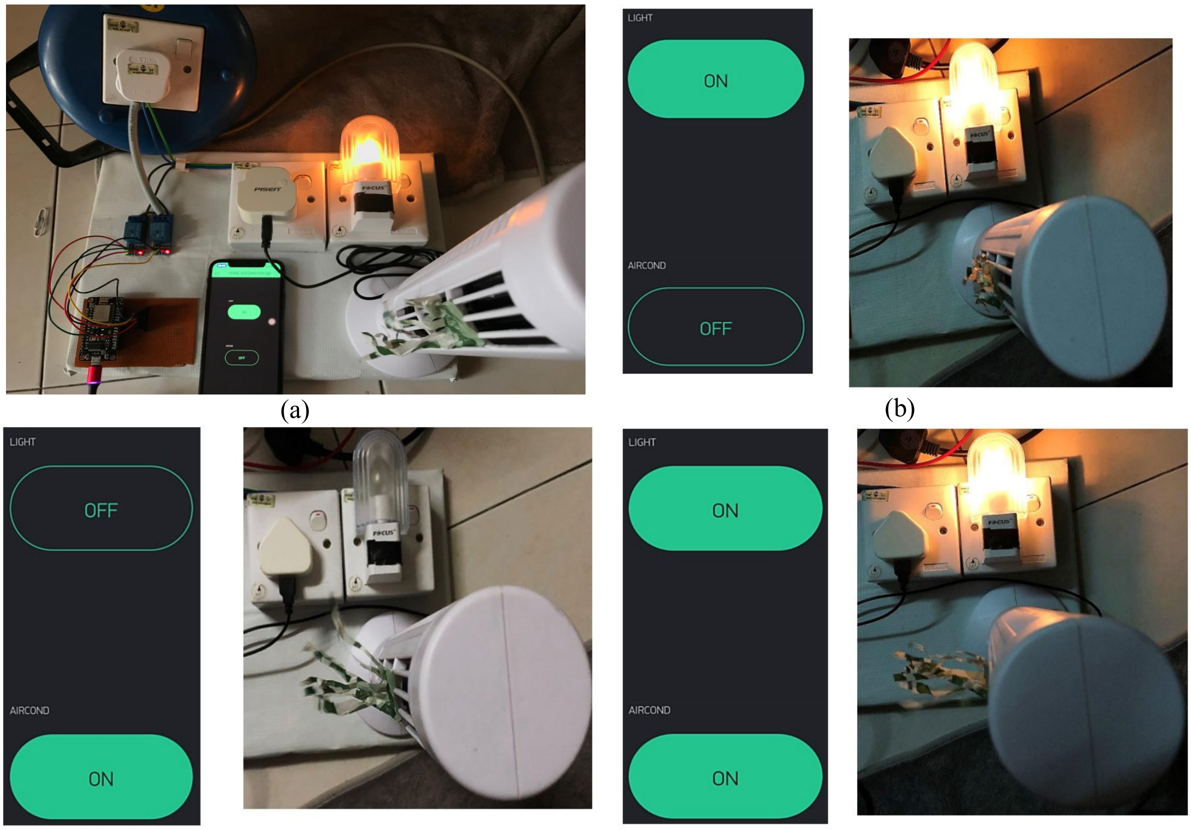

(a) (b)

(c) (d)

Figure 14: (a) home automation setup, (b), (c), (d) real-time status of home appliances compared with Blynk apps.

4. CONCLUSION

As conclusion, the speech/voice-controlled smart wheelchair was successfully developed with the additional feature which is home automation. The whole system was performed in the IoT platform. This automated wheelchair can be activated by the simple voice commands to steer the wheelchair to help the physically disabled person especially the user with the arm and hand impairments. The safety of the user is also more secure with the real-time streaming video applied from the wheelchair to the caretakers. Therefore, the developed smart wheelchair system with speech/voice-controlled provides easy access for the impaired person and this system is useful for the caretakers.

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