Faculty of Electronics and Computer Technology and Engineering

DEVELOPMENT OF A SOLAR POWERED CLEANING ROBOT USING ARDUINO FOR SOLAR PANEL ROOF CLEANING

LIEW WEN RUI

Bachelor of Computer Engineering Technology (Computer Systems) with Honours

2024

DEVELOPMENT OF A SOLAR POWERED CLEANING ROBOT USING ARDUINO FOR SOLAR PANEL ROOF CLEANING

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**A project report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Computer Engineering Technology (Computer Systems) with Honours**

Faculty of Electronics and Computer Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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FAKULTI TEKNOLOGI KEJUTERAAN ELEKTRIK DAN ELEKTRONIK

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DEDICATION

To my dear family and friends, your unwavering encouragement have been a constant source of strength. Your belief in my abilities has fuelled my determination to strive for excellence. Thank you for being the pillars of support that I can always lean on.

and

To Final Year Project supervisor, TS. DR. HASRUL 'NISHAM BIN ROSLY, your passion for teaching and commitment to fostering a positive learning environment have left an indelible mark on my educational experience. Your insightful feedback, constructive criticism, and genuine interest in our intellectual growth have been instrumental in shaping my academic endeavours.

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ABSTRACT

The most common form of solar energy used today are photovoltaic solar panels, which absorb the sunlight and directly convert the sun's radiation into electricity. Hence, by the rise of the solar technology, solar energy and solar panels are closely interconnected, as solar panels are the primary technology used to harness solar energy. However, the effectiveness of solar panels can be compromised by the accumulation of dust, dirt, and debris which are leading to reduced energy production and increased the maintenance costs. Large-scale solar installations are frequently unsuitable for manual cleaning techniques which are labour-intensive and time-consuming. Additionally, the manual cleaning techniques provide safety risks to the environment and workers, particularly on sloping or height roofs. The solar panel cleaning robot is an innovative solution designed to automate the cleaning process of solar panels roof, promoting the maximum effectiveness and efficiency of performance. This project utilizes an Arduino-based system that integrates various components such as an ultrasonic sensor, motor driver, and rechargeable battery. The robot provides the functions of detecting obstacles using ultrasonic sensor, controlling the movement and rotation of the motors and ultilizing a brush as cleaning technique to effectively clean the surface of solar panels. The software requirement of this project relies on the Arduino IDE which acts as the programming environment for code development, compilation and uploading to Arduino board. The potential of this project for commercialize depends on its applicability to solar panel installation companies. By incorporating the solar panel cleaning robot into their installation business, it can provide automated cleaning solutions, boost energy efficiency, minimise maintenance efforts and guarantee the optimal performance of solar panels installations. This project has the potential for commercialization due to its emphasis on automation, efficiency and sustainability of solar panels roof cleaning. The solar panel cleaning robot provides an inventive and affordable solution to increase the efficiency and longevity of solar panels in the renewable energy sector by overcoming the difficulties associated with manual traditional cleaning techniques.

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ABSTRAK

Penggunaan tenaga suria yang paling biasa hari ini adalah menggunakan panel solar fotovoltaik, yang menyerap cahaya matahari dan secara langsung menukar sinaran matahari kepada elektrik. Oleh itu, dengan peningkatan teknologi suria, tenaga suria dan panel suria saling berkait rapat, kerana panel suria adalah teknologi utama yang digunakan untuk memanfaatkan tenaga suria. Walau bagaimanapun, keberkesanan panel solar boleh terjejas oleh pengumpulan habuk, kekotoran dan serpihan yang membawa kepada pengurangan pengeluaran tenaga dan peningkatan kos penyelenggaraan. Pemasangan solar berskala besar selalunya tidak sesuai untuk teknik pembersihan manual yang memerlukan tenaga kerja dan memakan masa. Selain itu, teknik pembersihan manual memberikan risiko keselamatan kepada alam sekitar dan pekerja, terutamanya pada bumbung yang landai atau tinggi. Robot pembersihan panel solar ialah penyelesaian inovatif yang direka untuk mengautomasikan proses pembersihan bumbung panel solar, menggalakkan keberkesanan dan kecekapan prestasi maksimum. Projek ini menggunakan sistem berasaskan Arduino yang mengintegrasikan pelbagai komponen seperti sensor ultrasonik, pemandu motor, dan bateri boleh dicas semula. Robot ini menyediakan fungsi mengesan halangan menggunakan sensor ultrasonik, mengawal pergerakan dan putaran motor dan menggunakan berus sebagai teknik pembersihan untuk membersihkan permukaan panel solar dengan berkesan. Keperluan perisian projek ini bergantung pada IDE Arduino yang bertindak sebagai persekitaran pengaturcaraan untuk pembangunan kod, penyusunan dan muat naik ke papan Arduino. Potensi projek ini untuk dikomersialkan bergantung kepada kebolehgunaannya kepada syarikat pemasangan panel solar. Dengan menggabungkan robot pembersihan panel solar ke dalam perniagaan pemasangan mereka, ia boleh menyediakan penyelesaian pembersihan automatik, meningkatkan kecekapan tenaga, meminimumkan usaha penyelenggaraan dan menjamin prestasi optimum pemasangan panel solar. Projek ini berpotensi untuk dikomersialkan kerana penekanannya pada automasi, kecekapan dan kemampanan pembersihan bumbung panel solar. Robot pembersihan panel solar menyediakan penyelesaian inventif dan berpatutan untuk meningkatkan kecekapan dan jangka hayat panel solar dalam sektor tenaga boleh diperbaharui dengan mengatasi kesukaran yang berkaitan dengan teknik pembersihan tradisional manual.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

In recent years, statistic shows that the specter of climate change has loomed large. There have been remarkable changes to the Earth's climate system in the past few decades such as rising of temperature, melting of ice caps, unpredicatable weather patterns and an increase in natural calamities. In this critical context, solar energy has significantly gained traction in this crucial setting and is attracting the attention of government, corporations and individuals alike. It is different from the traditional energy sources like coal or natural gas, solar energy depends on absorbing sunlight and using photovoltaic (PV) cells to turn it into electrical energy. Solar energy is renewable since it comes from the sun, a constant supply of energy. As long as the sun shines, solar energy will remain accessible, making it an inexhaustible resource.

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Since the solar power is rapidly gaining popularity, the demand of solar panels' adoption is increasing. Hence, regular cleaning of solar panels is essential for ensuring optimal energy generation. There are several techniques used to clean solar panels but most of them are traditional cleaning techniques such as hand cleaning or water-based systems. These can be time-consuming, labor-intensive, and frequently harmful to the environment due to the use of chemical detergent.

Therefore, the development of a Solar Powered Cleaning Robot using Arduino presents an innovative solution. The goal of this project is to create an autonomous robot that can effectively clean rooftop solar panels. The robot can function independently and have a minimal influence on the environment by utilising solar energy. The development of the cleaning robot is made possible by the usage of Arduino, an open-source electronics platform. Due to its flexibility, Arduino may easily be used to integrate the different parts, sensors, and programming logic required for the robot's autonomous functioning. The robot can navigate rooftops, find and clean unclean solar panels, and ensure comprehensive and accurate cleaning via its capacity to perceive and adapt to its environment.

1.2 Problem Statement

Solar panels are becoming more widely used as a renewable energy source, however maintaining them presents considerable difficulties. Both manual cleaning techniques and water-based systems require a lot of labour, take a lot of time and are frequently not environmentally friendly. As a result, there is a need for an effective, affordable, and long-lasting method of cleaning solar panel roofs.

The traditional cleaning methods are not so effective to solve the unique challenges brought on by rooftop solar panels. The manual labour needed for cleaning causes time-consuming and costly, particularly for large-scale solar installations. The usage of water-based systems can also result in water waste, possible panel damage and pollution of the surrounding areas.

Furthermore, the efficiency of traditional cleaning techniques is limited by a lack of automation and flexibility. Without autonomy, cleaning schedules are frequently erratic, resulting in inadequate energy output and decreased system effectiveness. As the number of solar panel installations rises, this problem gets more serious and requires frequent and consistent cleaning.

The current traditional cleaning techniques used to maintain solar panel rooftops provide safety risks to the environment and workers. These techniques rely on workers to physically reach rooftops and navigate around solar panels, which may be risky, particularly on sloping or height roofs. Accidental slips, falls and other mishaps pose a persistent threat of serious injury or even fatality. Additionally, cleaning from a height raises the possibility of harming the solar panels or other structures, which would need expensive repairs and reduce energy output of the solar panels.

1.3 Project Objective

The objectives are as follows:

a) To design and develop a solar-powered cleaning robot that can clean solar panel roofs.

b) To program an Arduino microcontroller to manage the robot's movement, sensors, and cleaning operation.

c) To analyse the performance of the robot.

1.4 Scope of Project

The scope of this project encompasses the design, development and implementation of a solar-powered cleaning robot using Arduino for the purpose of solar panel rooftops cleaning. In order to achieve the objectives of this project, the scope aims to solve the problems with the traditional cleaning techniques and offer a creative and long-lasting alternative. The key areas within this project include:

a) The robot aims to move straight and clean on the flat rectangular solar panel on the ground.

b) The size of the solar panel to be cleaned is 120 cm × 30 cm.

c) Design and development on the mechanical structure of the cleaning robot and implement the solar power system for the robot to operate on its own, reducing the reliance on external power sources.

d) Using Arduino technology to integrate sensors and control systems, such as edge detection, navigation and cleaning up the scrap papers which are the cleanup target.

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CHAPTER 2

LITERATURE REVIEW

2.1 Solar Energy

Solar energy is derived from the sun, the Earth's surface receives a large amount of solar radiation, which gives rise to solar energy and the potential for photovoltaic (PV) self-powered applications. The cost of PV generating is rapidly decreasing as a result of ongoing technical advancement [1]. Utilizing solar energy has become a revolutionary and essential source of renewable energy. Solar energy has several advantages for a sustainable future since it is abundant and clean. The practicality and cost-effectiveness of solar technology have grown due to developments in more efficient solar panels and energy storage devices. Fossil fuels may be replaced by solar energy, which is safer for the environment and helps to fight climate change [2]. Additionally, solar power systems may be installed at several sizes, from small rooftop installations to massive solar farms, which helps to promote decentralized and resilient energy generation. Solar energy stands out as a critical pillar in our search for a cleaner and more sustainable world as we work to transition to a low-carbon future.

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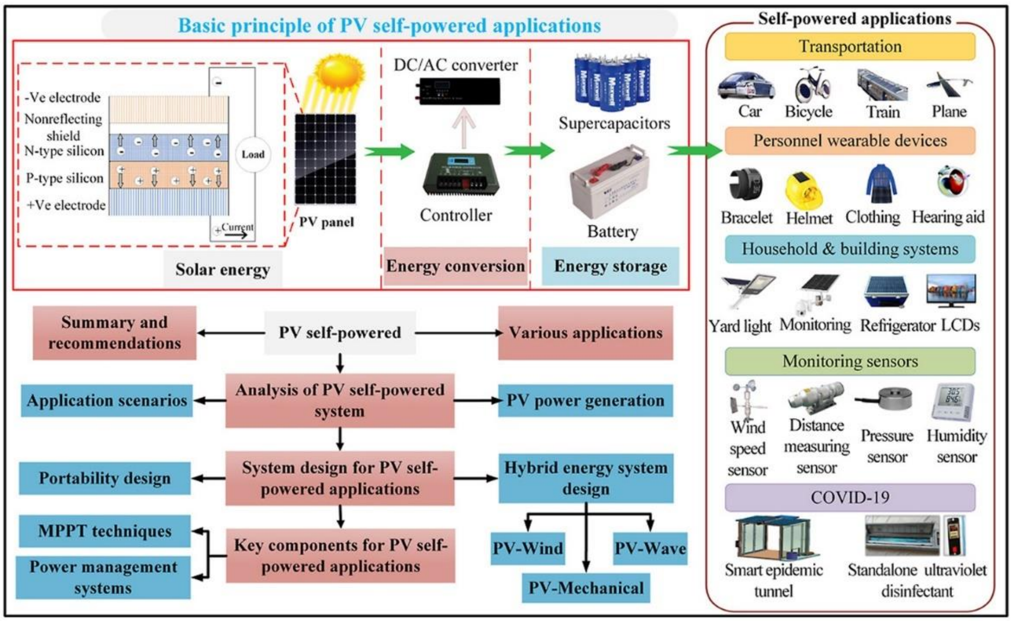

Figure 2.1 Architecture of PV self-powered technologies [1]

Figure 2.1 shows the PV self-powered technologies from various aspects. This describe the PV self-powered systems are more dependable source of electricity then traditional battery power. Solar energy is readily available, can handle applications' power supply issues, and is sustainable development-friendly compared to traditional battery power supply's capacity limitations.

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2.2 Impact of COVID-19 on Renewable Energy (RE) sector in Malaysia

In Malaysia, the coronavirus disease 2019 (COVID-19) has caused destruction in a number of industries. Malaysia excels at harvesting solar energy, biomass energy, and hydro energy from renewable sources, yet after years of advancement, the effects of COVID-19 on these areas continue to be considerable [3]. Solar energy projects are delayed as a result of the suspension of solar panel imports. In parallel, biomass had decreased output as employees were sent home as a precaution against COVID-19. The same is true for hydroelectric dams, where a single incident might result in a cluster, again postponing the entire project.

Table 2.1 Summarized table of the potential of RE sectors [3]

RE Sectors	Current Impacts	Future Impacts	Future Projection
Solar Energy	• Minimize reliance on other countires for manufacturing and begin local manufacturing processes. • Purchasing of additional solar panels in storage as backups.	• A drop in oil prices will result in solar panel investments. • Due to that fact, governments would place fewer incentives on fossil fuels to promote solar panel investments.	• Malaysia should see an increase in solar energy development, and a transition from fossil fuels may be expected as well.
Biomass	• Tripling the price of rice due to panic buying and storing, hence affecting the biomass output. • Coutrywide lockdown implemented has affected the operation of palm kernel shell suppliers. • Labour shortages due to travel restrictions imposed.	• Introducing job oppurtunities for locals in the sector due to the shortage of foreign workers. • Biomass materials are used to prepare graphene-like materials which can be used on surgical masks besides being used in sensors to detect the virus.	• Local unemployment rates should see a drop as the local farmers area more accepting of local labour workers. • If more resources area devoted to developing and understanding graphene-like materials (derived from biomass), Malaysia may be the pionner in inventing an organic virus detector.
Hydroelectric	• Health and safety measures need to be kept in check. • A single contagious case will spread and may cause the entire site to shut down.	• Constant studies and research are vital to improving hydro efficiencies. • Malaysians should begin looking toward hydropower generation as Malaysia has an abundance of flowing rivers.	• Hydroelectric development in Malaysia should still be able to proceed as planned, albeit with some delays due to this pandemic.

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Table 2.1 shows the potential of the RE sectors in currect and future impact of COVID-19. The development of Solar Energy in Malaysia is predicted to increase and replace the fossil fuels as primary energy source. Table 2.1 also compares the Solar Energy with other renewable energy showing the future projection of each RE sector.

2.2.1 Solar Energy in Malaysia

Solar energy is plentiful, cost-free, and eco-friendly because it doesn't pollute the environment. Malaysia experiences year-round regular rainfall in a hot, muggy environment. The nation is favourable for using solar energy since it receives a mean daily solar radiation of between 4.7 and 6.5 kWh/m2 [4]. Due to Malaysia's prodigious sunlight, solar photovoltaic (PV) systems have advanced, and the populace is become more aware of its potential. To encourage the use of solar and other renewable energy sources in the nation, the government has put into place programmes including net energy metering (NEM), feed-in tariff (FIT), and large-scale solar (LSS) [5]. In Malaysia, renewable energy currently accounts for 8% of total energy generation, with plans to increase it to 25% by 2025. The COVID-19 epidemic has caused the solar energy industry to face a number of difficulties, including labour shortages, project delays, investor pullouts, and supply chain disruptions. SolarVest, +Solar, Green Energy Resources, SOLS energy, and Pathgreen Energy are the example of notable solar energy businesses in Malaysia. Prior to the pandemic, it was anticipated that Malaysia's installed solar energy capacity will increase from 2021 to 2026 at a compound annual growth rate of above 10%, reaching 2.07 GW in 2026 [3].

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Table 2.2 Statistics of installed capacity and electricity generation in Malaysia compared to the rest of the world from 2010 to 2019 [5]

Year	Installed capacity, MW (Malaysia)	Electricity generation, GWh (Malaysia)	Insatalled capacity, MW (Rest of the world)	Electricity generation, GWh (Rest of the world)
2010	0.54	0.67	40276.67	32160.38
2011	0.54	0.67	72029.69	62443.37
2012	25.10	30.88	101511.21	96351.81
2013	97.12	53.74	135740.15	131701.12
2014	165.78	190.51	171518.92	183943.37
2015	229.10	275.41	217242.52	242371.88
2016	278.80	326.23	290961.18	314053.25
2017	370.07	333.02	383597.83	425872.64
2018	536.02	N/A	483078.20	N/A
2019	882.02	N/A	580159	N/A

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Table 2.2 shows the statistics of installed capacity and electricity generation of solar panels in Malaysia compared to the rest of the world from 2010 to 2019 year. As the result shown in Table 2.2, the number of solar PV installations has dramatically grown in Malaysia. The use of PV technology in conjunction with the mini-grids allows for the generation of power and the distribution of it throughout the whole country.

2.3 Microcontroller

A microcontroller is a small compact integrated computer on a single IC chip. It basically consists of at least one processor core (CPU), memory and input/output ports on a single chip. It can carry out a variety of functions in a wide range of applications, from home appliances and automotive systems to industrial automation and Internet of Things (IoT) devices. They provide precise control, real-time processing, interface capabilities, making them essential components for building intelligent and interconnected electronic systems.

2.3.1 Arduino Microcontroller

Arduino is an open-source hardware and software platform that provides an accessible and beginner-friendly approach to start with electronics and programming. It offers a range of microcontroller boards with an easy-to-use development environment, making it popular among hobbyists, students, and professionals alike. Arduino enables speedy prototyping and the integration of several sensors, actuators, and modules due to its wide user base, extensive library of prewritten code, and extensive library of users. Arduino platform can be divided into hardware and software where Arduino development board as hardware and Arduino Integrated Development Environment (IDE) as software [6].

Table 2.3 **Comparison of Arduino, Raspberry Pi B+ and ESP-8266 Wi-Fi module** [7]

Parameters	**Arduino Uno**	**Raspberry Pi B+**	**ESP-8266**
Processor	ATMega328P	Quad-core ARM Cortex A53	-
GPU	-	Broadcom VideoCore IV with 400 MHz	-
Operating voltage	5V	5V	3.3V
Clock speed	16 MHz	1.2 GHz	26 MHz – 52 MHz
System memory	2 kB	1 GB	< 45 kB
Flash memory	32 kB	-	Up to 128 MB
EEPROM	1 kB	-	-
Communication supported	IEEE 802.11 b/g/n, IEEE802.15.4, 433RF, BLE 4.0 via Shield	IEEE 802.11 b/g/n, IEEE 802.15.4, 433RF, BLE 4.0, Ethernet Serial	IEEE 802.11 b/g/n
Development environment	Arduino IDE	Any Linux compatible IDE	Arduino IDE, Lua Loader
Programming language	Wiring, C, C++	Python, C, C++, Java, Scratch, Ruby	Wiring, C, C++
I/O Connectivity	SPI, 12C, UART, GPIO	SPI, DSI, UART, SDIO, CSI, GPIO	UART, GPIO

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Table 2.3 shows the difference between three common microcontrollers among the engineers. In this project, the Arduino Uno microcontroller board will be the target microcontroller unit in this project.

2.3.1.1 Arduino Uno

Arduino Uno is a common and popular microcontroller board based on the ATMega328P microcontroller with 14 digital input and output ports. It contains a reset button in addition to a power port and a USB connector for the purpose of delivering data wirelessly or via the calculator [8]. ATMega328P which is a high-performance Microchip 8-bit AVR RISC-based microcontroller provides a 16 MHz of clock speed. It combines 2 kB system memory, 1 kB of EEPROM and 32 kB of flash memory which are sufficient for system development. This is due to the image, video and audio storage that are not required in this project.

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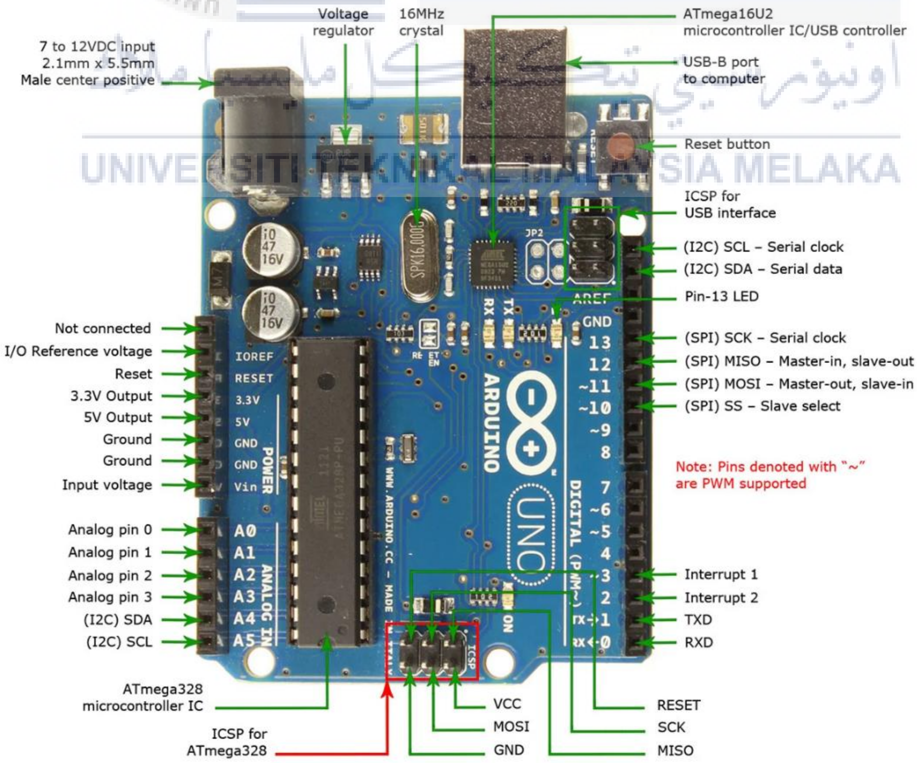

Figure 2.2 A labeled pin diagram of Arduino Uno Board [6]

Figure 2.2 shows the classification of parts in Arduino Uno board. This board consists of USB plug, Reset button, Analog pins, Digital I/O pins, and Power and GND pins.

2.4 Effect of Dust on Power Loss in Solar Panel

On solar panels, the air dust particles may have a big significant impact on their performance and power output. The quantity of sunlight that reaches the photovoltaic cells is decreased as dust particles collect on the surface of the panels. As a result, there is a barrier that prevents solar radiation from being absorbed, which lowers the efficiency of energy conversion [9]. Depending on the amount of dust buildup and how clean the panels are, dust deposition can cause a loss in power output of a few percentages up to 50% - 60% [10]. To minimize the negative impacts of dust and guarantee efficient energy generation, regular cleaning and maintenance of solar panels are important. The effectiveness and overall performance of the solar energy may be improved by keeping the panels clean.

Table 2.4 Performance of power obtained from different types of dust samples [10]

Dust sample type	Weight (g)	Minimum power (W)	Weight (g)	Maximum power (W)
Badarpur sand 1	10	6.50	50	14.12
Badarpur sand 2	10	7.09	50	14.88
Fly ash	5	9.27	25	14.77
Rice husk	5	3.88	25	15.48
Chalk powder	5	8.54	25	17.40
Brick powder	5	6.66	25	15.04
Sand	5	7.20	25	14.89

Table 2.4 shows the minimum and maximum power obtained from the solar panel after using different forms of dust samples. Based on this table, the efficiency of solar panels in terms of power can be reduced up to 60% because of air dust particles.

2.5 Cleaning Methods for Removing Dust from Solar Panels

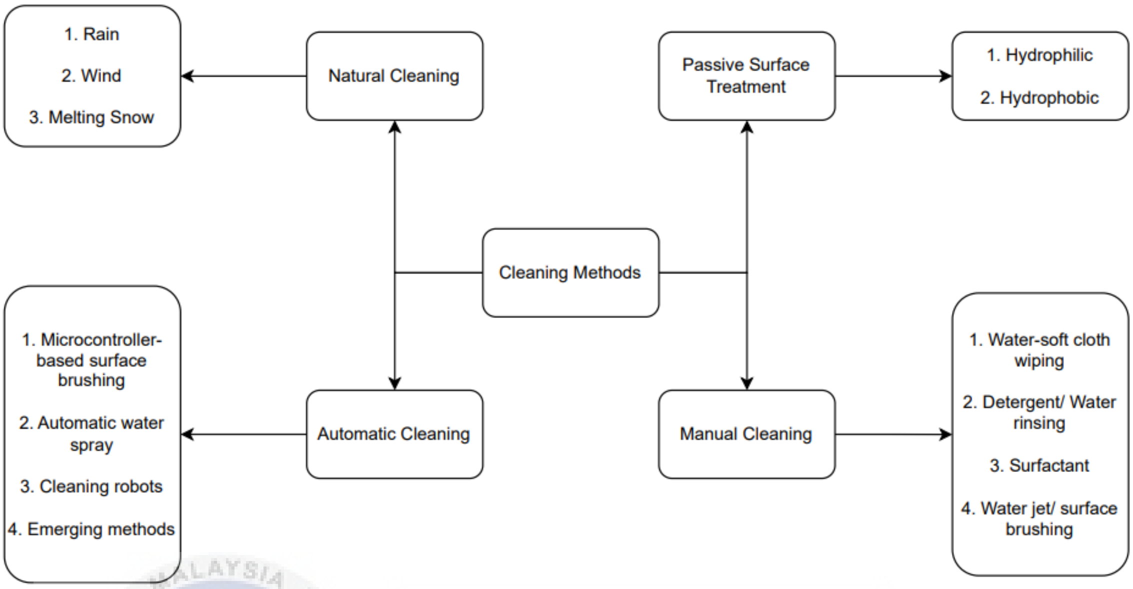

Figure 2.3 Different cleaning methods to remove dust from solar panels [11]

Figure 2.3 shows the different cleaning methods and its details for removing dust from solar panels. From Figure 2.3, manual cleaning method can be considered as conventional cleaning technique while automatic cleaning as the modern cleaning technique. The manual cleaning method involves physically accessing solar panel roofs and manually removing dirt, dust, and debris using tools such as brushes, squeegees, or soft cloths. Workers typically climb onto rooftops, often using ladders or harnesses, and clean the panels by hand. This method is labor-intensive and time-consuming, requiring skilled personnel to perform the task. However, it is associated with safety risks, including falls, accidents, and potential damage to panels or roof structures if not executed with care. Water-based cleaning systems utilize water and cleaning agents to remove dirt and grime from solar panels. This method involves spraying water onto the panels, either manually or with the help of automated systems, followed by brushing or scrubbing to dislodge the contaminants. The water, along with the loosened dirt, is then allowed to flow off the panels or collected for proper disposal.

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While water-based systems can effectively clean panels, they have drawbacks such as high-water consumption, which can lead to water wastage, especially in areas with water scarcity. Additionally, the use of cleaning agents may introduce environmental concerns if not properly managed or disposed of, potentially polluting water sources or damaging ecosystems.

On the other hand, the automatic cleaning method refers to the use of robotic systems or automated mechanisms to clean solar panels without the need for manual intervention [12]. These systems are designed to perform cleaning operations autonomously or under remote control. They are equipped with cleaning mechanisms such as brushes, wipers, or sprayers that are activated based on predetermined schedules or sensor inputs. Robotic cleaning solutions employ autonomous robots that navigate the surface of solar panels, detecting and removing dirt and debris. These robots are equipped with sensors to detect obstacles, avoid collisions, and ensure precise cleaning. They can operate on various terrains and adapt to different panel configurations. By utilizing advanced algorithms and control systems, they optimize cleaning efficiency and coverage. Automatic cleaning offers several advantages, including increased efficiency, reduced labor requirements, and improved safety by eliminating the need for manual rooftop access. It can ensure consistent and thorough cleaning, minimizing the risk of performance degradation due to dirt accumulation [12]. Additionally, some systems incorporate smart features like remote monitoring and data analysis, allowing for optimization of cleaning schedules and performance evaluation.

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2.6 Comparison between previous projects and this project

There are some researches has been conducted from previous journals, articles and papers to gain a comprehensive understanding of the existing developed products, theories, technologies and methodologies. There are 5 studies that are similar to this project but with different methods as follows:

i) Design of a Dust Cleaning Machine to Reduce Dust Soiling on Solar PV Panels in Ghana [13].

ii) Automatic Solar Panel Cleaning System Based on Arduino for Dust Removal [14].

iii) Design and Development of a Cleaning Robot for Solar Panels with Sun Tracking [15].

iv) Robotic Device for Cleaning and Monitoring Photovoltaic Panel Arrays [16].

v) Designing and Manufacturing a Robot for Dry-Cleaning PV Solar Panels [17].

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Table 2.5 Comparison between previous projects and this project

Project	Similarities	Differences	References
i)	• Water-based cleaning technique. • Using brush as the cleaning tool.	• Solar panel is put on the mounting rack with the cleaning machine. • The movement of the cleaning machine depends on the rubber wheels on the rail of the rack.	[13]

Project	Similarities	Differences	References
		• Using direct current to drive motor-driven wheel. • No microcontroller	
ii)	• Using Arduino Uno microcontroller. • Using brush as the cleaning tool. • Using solar power as source energy for the robot.	• Aims for dust removal without water-based cleaning technique. • LDR sensor is used for tracking sunlight. • The rail is required for the movement of the robot.	[14]
iii)	• Using Arduino Uno microcontroller. • Using solar power as source energy for the robot. • Using brush as the cleaning tool.	• The robot is allocated on the track of solar panel during the cleaning process. • Using solar tracker system to track the sunlight. • Dry cleaning technique. • The robot is installed on the solar panel to periodically cleaning the solar panel.	[15]
iv)	• Using Arduino Uno microcontroller.	• Using Blynk apps as interface to control the movement of robot.	[16]

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Project	Similarities	Differences	References
	• Using solar power as source energy for the robot. • The robot can move in any direction instead of the default track direction.	• Using microfiber mop as cleaning tool. • Using lead acid rechargeable battery as power source. • Using camera module to monitor the PV panels surface condition.	
v)	• Using Arduino Uno microcontroller. • Using brush as the cleaning tool.	• Using lead acid rechargeable battery as power source. • The robot is connected to the trolley which will allow it to move along the track during the cleaning process. • Using Bluetooth RC to control the movement of the robot. • Dry cleaning method.	[17]

Table 2.5 shows the similarities and differences between the previous projects and this project. Based on Table 2.5, most of the research is related to solar panel cleaning robot using Arduino that utilizes dry cleaning method and the fix track movement control.

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2.7 Summary

This chapter tells topics regarding the title of this project on global issue, society issue and technology information. Based on the journals, solar panel adoption in Malaysia has been growing steadily in recent years especially during period of COVID-19 pandemic, driven by various factors and initiatives. The trend of solar panel adoption in Malaysia is positive, with increasing government support, declining costs, growing awareness, and a flourishing solar industry. This trend is expected to continue as Malaysia strives to increase its renewable energy capacity and reduce greenhouse gas emissions. However, the trend of solar panel cleaning in Malaysia is still emerging as there is lack of awareness of solar energy and professional cleaning services. Therefore, a solar panel cleaning robot provides efficient, safe, and effective cleaning solutions for maintaining the performance of solar panels.

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CHAPTER 3

METHODOLOGY

3.1 Flow of Modules of the System

The flowchart is used to illustrate the process and the procedure of any system in this project. It explains the steps of algorithms in a sequence to allow us to proceed with the next operation as well as how it should be carried out.

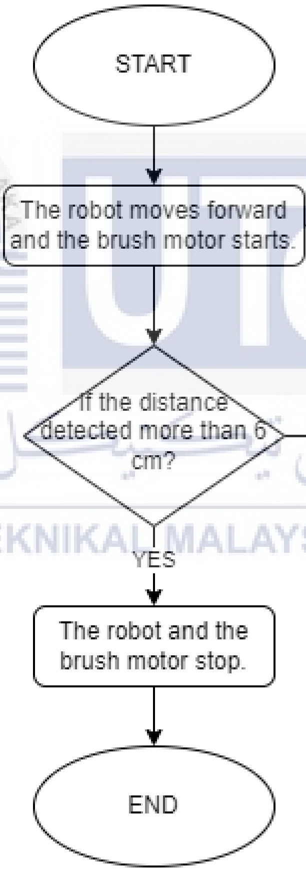

Figure 3.1 Flowchart of robot cleaning process

Figure 3.1 shows the workflow of the cleaning process in this project. When the system starts, the ultrasonic sensor will begin to sense the distance between the edge of the solar panel and the front part of the robot. If the distance detected is lower or equal to the limit value set (6 cm), the robot will move forward and start cleaning tools. Otherwise, the cleaning tools and robot will stop their operations.

3.2 System Requirements

This project require two types of components in the system requirement: the hardware component and the software component.

3.2.1 Hardware Requirements

All the necessary hardware components that will be used in this project. The main components that will be used in this project are Arduino Uno, ultrasonic sensor, motor driver L298, DC motor, rechargeable battery, brush, wheels, and 7V solar panel.

3.2.1.1 Arduino Uno

Arduino Uno microcontroller serves as the main controller for the robot. It provides the necessary computational power and interfaces with various components to perform specific functions. It is used to controls the motors connected to the robot wheels. By manipulating the motor control pins, it can make the robot move forward, backward, turn left, turn right, or stop. Arduino also interfaces with the ultrasonic sensor to detect obstacles in front of the robot. It triggers the sensor and measures the time it takes for the ultrasonic waves to bounce back, allowing it to calculate the distance to an obstacle. Overall, the Arduino board acts as the brain of the solar panel cleaning robot, coordinating the motor movements, interpreting sensor data, and executing the desired actions based on the programmed logic.

3.2.1.2 Ultrasonic Sensor

The ultrasonic sensor in this solar panel cleaning robot project serves the purpose of obstacle detection. It measures the distance between the robot and any obstacles in its path using ultrasonic waves [18]. The ultrasonic sensor emits ultrasonic waves and measures the time it takes for the waves to bounce back after hitting an object. By knowing the speed of sound in the air, the sensor can calculate the distance to the obstacle. The ultrasonic sensor enhances the autonomy of the solar panel cleaning robot by providing real-time information about the environment. It enables the robot to autonomously navigate and avoid obstacles, making the cleaning process more efficient and reliable.

3.2.1.3 Motor Driver L298

The motor driver L298 in this project is responsible for controlling the movement of the robot's motors. It serves as an interface between the Arduino and the motors, providing the necessary power and control signals. The L298 motor driver can control the direction and speed of the motors. It has separate control inputs for each motor, allowing independent control of the left and right wheels or other motor configurations. The L298 motor driver utilizes an H-bridge configuration, which allows the motors to be driven in both forward and reverse directions. By controlling the logic levels on the motor driver's input pins, the Arduino can determine the motor rotation direction. The L298 motor driver acts as a bridge between the Arduino and the motors, providing power amplification, bidirectional motor control, and other protective features.

3.2.1.4 DC Motor

The function of the motor in this project is to drive the movement of the solar panel cleaning robot. The motor is responsible for converting electrical energy into mechanical

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energy, allowing the robot to perform various actions such as moving forward, backward, turning, or stopping. The motor plays a crucial role in enabling the robot's mobility and maneuverability.

3.2.1.5 Rechargeable battery

The rechargeable battery serves as the main power source for the robot. It provides the necessary electrical energy to operate the Arduino, motor driver, motors, and other components of the robot. The battery allows the robot to operate independently of a constant external power supply.

3.2.1.6 Brush

The function of the brush in this project is to physically clean the surface of the solar panels. The brush is designed to effectively remove dust, dirt, leaves, and other debris that accumulate on the surface of the solar panels over time. These particles can reduce the efficiency of the panels by blocking sunlight, so the brush helps keep the panels clean for optimal performance. The brush uses mechanical action, such as bristles or rotating brushes, to agitate and dislodge the particles adhered to the surface of the solar panels. This action helps loosen and sweep away the debris, allowing for a thorough cleaning.

3.2.1.7 Wheels

The function of the wheels in this project is to provide traction, stability, and mobility to the solar panel cleaning robot. The wheels help the robot maintain traction on various surfaces, such as smooth or uneven terrain. The rubber material provides grip and prevents slippage, allowing the robot to move efficiently even in challenging environments. The wheels and rubber tracks enable the robot to move in different directions. By controlling the rotation of the wheels on each side of the robot independently, it can execute movements like moving forward, backward, turning left, turning right, or rotating in place. This mobility allows the robot to navigate and clean the solar panels effectively. The rubber of wheels can help dampen noise and vibration generated by the robot's movement. They act as shock absorbers, reducing the impact and vibrations transmitted to the robot's structure, resulting in quieter operation and improved user experience.

3.2.1.8 7V Solar Panel

The function of the 7V solar panel in this project is to harness solar energy and convert it into electrical power to charge the robot's battery or directly power its components. The 7V solar panel produces a direct current (DC) output voltage of 7 volts. This voltage level is typically suitable for powering low-power electronic components and charging batteries used in the solar panel cleaning robot.

3.3 Software Requirements

The software requirement in this project is to provide the necessary tools and libraries to help in designing, simulation, program, and control the Arduino board for monitoring the cleaning robot. They also work as well as interface with the various components and sensors used in the solar panel cleaning robot. They enable efficient code development, reliable hardware control, and seamless interaction between the Arduino board and the project's peripherals. The main software tools that will be used in this project are Proteus 8 Professionals and Arduino IDE.

3.3.1 Proteus 8 Professionals

Figure 3.2 Proteus 8 Professionals' logo

Figure 3.2 shows the simulation apps, Proteus 8 professionals' logo. Proteus is a powerful CAD software tool that can be used to simulate and test the electrical circuitry of the solar panel cleaning robot during designing and developing of this project. Proteus allows you to design and simulate the electrical circuitry of the robot, including the connections between the Arduino board, motor driver, sensors, and other components. It provides a wide range of component libraries, including Arduino Uno, ultrasonic sensors, motor driver L298 and other electrical components. Proteus serves as a valuable tool in the development process of the solar panel cleaning robot project. It helps in designing, testing, and optimizing the electrical circuitry, ensuring its functionality and reliability before moving to the physical implementation stage.

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3.3.2 Arduino IDE

Figure 3.3 Arduino IDE's logo

Figure 3.3 shows the Arduino IDE (Integrated Development Environment)'s logo. Arduino IDE is a software tool that can be used for programming and uploading code to Arduino board in this project. The Arduino IDE provides a text editor where you can write, edit, and organize your code for the solar panel cleaning robot. It supports the Arduino programming language, which is based on C/C++.

3.4 Cost and Budget

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Table 3.1 Cost of this project

Item	Quantity (pcs)	Expected Unit Price (RM)	Expected Total Price (RM)
Arduino Uno	1	75.00	75.00
Motor Driver L298	2	5.90	11.80
DC Motor	5	3.50	17.50
Ultrasonic Sensor	3	3.30	9.90
Rechargeable Battery	4	8.20	32.80

Item	Quantity (pcs)	Expected Unit Price (RM)	Expected Total Price (RM)
Brush	1	8.00	8.00
Acrylic Sheet A3	2	13.15	26.30
Wheels	4	1.70	6.80
Jumper Wires Bundle	1	4.60	4.60
10A Solar controller	1	10.90	10.90
7 V solar panel	1	39.30	39.30
TOTAL			**242.90**

Table 3.1 shows the total estimated cost of this project is RM 242.90. Prices for each item are collected online from Cytron Tech and Shopee. The prices may differ in the market based on the season. The software requirement is open-source platform and free of charge.

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3.5 The Architecture of the System

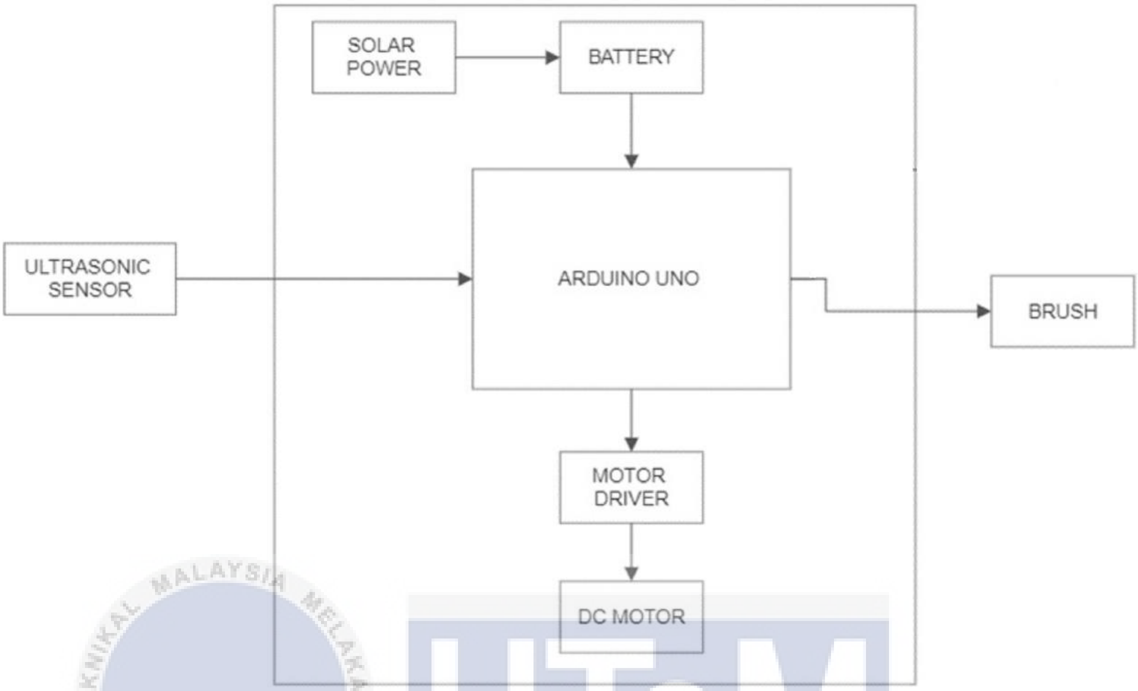

Figure 3.4 Block diagram of the system

Figure 3.4 shows the block diagram of the proposed solar panel cleaning robot. It includes the Arduino Uno as microcontroller unit, a battery connected to solar panel, ultrasonic sensors, motor driver with motors, and brush. Based on the information provided by the ultrasonic sensor, the microcontroller unit regulates the motion of the DC motor. Additionally, it chooses when to start the brushes for cleaning. An ultrasonic sensor in this system determines the proposed robot's movement distance. Static brushes that are mounted on the robot's front as the cleaning technique.

3.6 Testing and Evaluation

Unit testing and integration testing should be conducted to test the system functionality. The preliminary result should be ensured to meet the system expected output and requirement.

3.7 Completion of Final Report

The final report for this project must include all the relevant data in the form of introduction, literature review, methodology, preliminary results and lastly conclusions.

3.8 Project Planning

Appendix B in the appendix shows the Gantt chart which is used to present the progression for entire PSM 1 and PSM 2. It will outline all the tasks involved in this project with the present of timescales. The Logbook is also utilized to record weekly progression of PSM 1 and PSM 2.

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3.9 Summary

This chapter presents the proposed methodology in order to develop an effective and integrated solar powered cleaning robot using Arduino for solar panel roof cleaning. The primary focus of the proposed methodology is in accomplishing a simple, less rigorous and effective estimation in such a way that it would not cause a significant loss of accuracy of the results.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results and analysis on the development of solar powered cleaning robot using Arduino for solar panel roof cleaning. The results consist of testing for hardware circuit connections and the software codings and the testing for voltage and current used by the robot moving in straight line for 5s.

4.2 Result of hardware circuit connections

4.2.1 External appearance of the robot

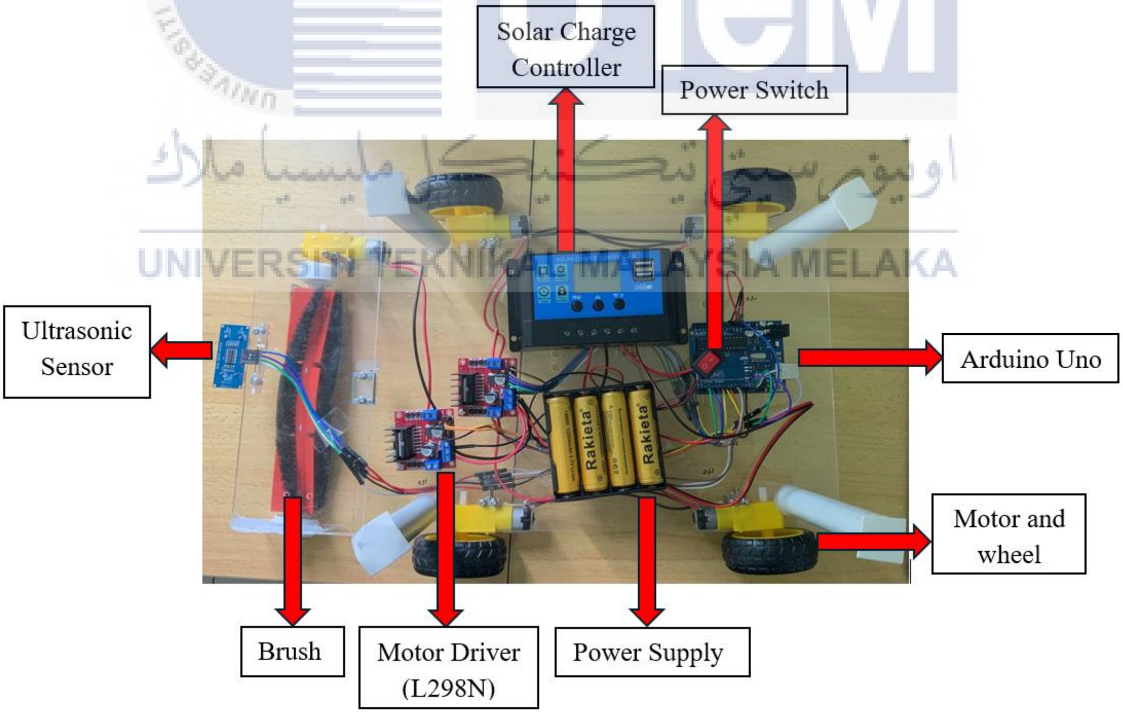

Figure 4.1 Hardware circuit

Figure 4.1 shows the physical hardware connection.

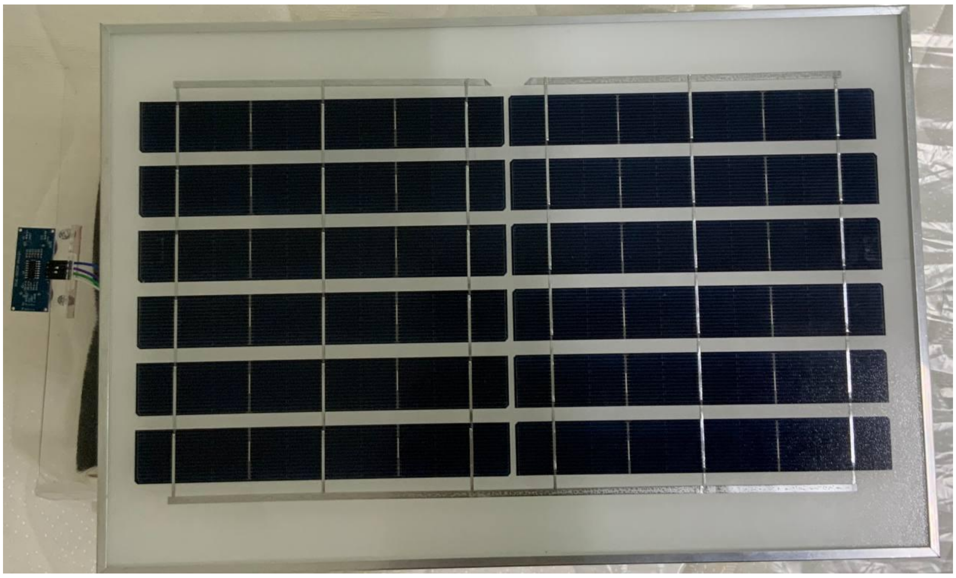

Figure 4.2 Top view of the robot

Figure 4.2 shows the view of the robot from top. The solar panel and the ultrasonic sensor can be oberserved from the top view.

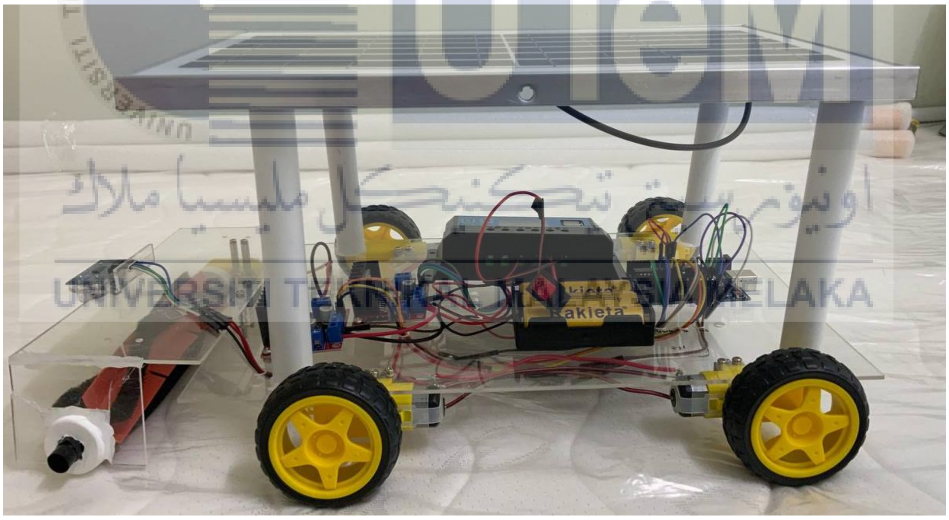

Figure 4.3 Side view of the robot

Figure 4.3 shows the side view of the robot. The solar panel is attached on the top of the robot to receive the sunlight and charge the rechargeable batteries. A ultrasonic sensor is attached in front of the robot to detect the roof edge. The brush as the cleaning tool connected in front of the robot while the motor drivers and Arduino Uno are connected to the rechargeable batteries.

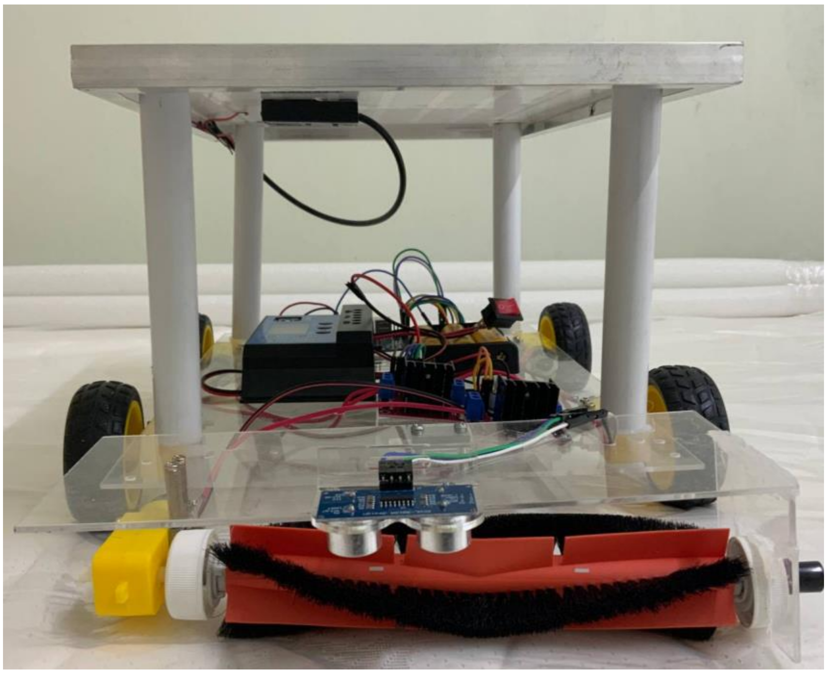

Figure 4.4 Front view of the robot

Figure 4.4 shows the view of the robot from the front side.

4.2.2 Testing of movements of the robot

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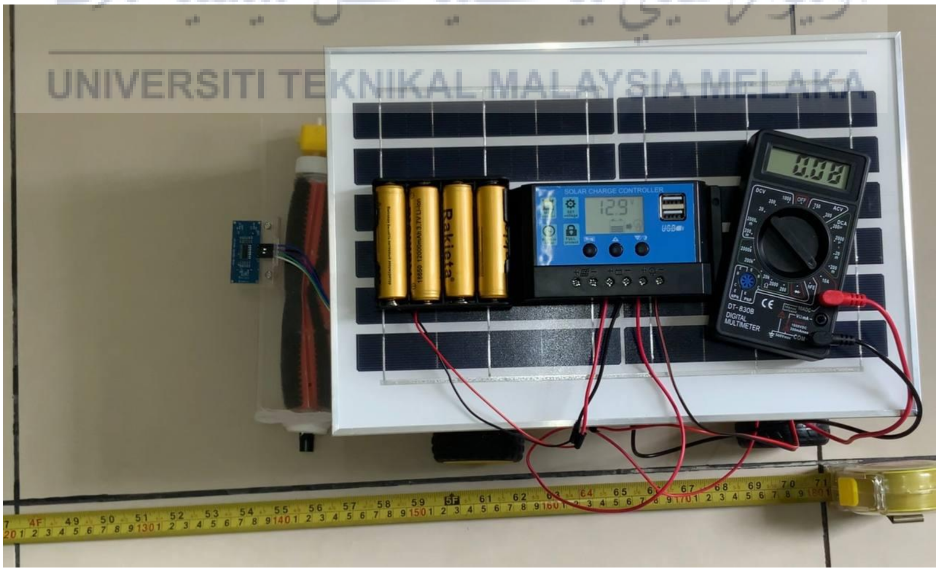

Figure 4.5 The robot is initially in static state.

Figure 4.5 shows the robot is initially in static state and ready to move in a straight line from the starting point (180 cm).

Figure 4.6 The robot moves for 5 seconds and stops.

Figure 4.6 shows the robot moves for 5 seconds and stops at the point of 75 cm. The robot moves in a straight line of 105 cm in 5 seconds.

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4.2.3 Testing of cleaning process of the robot

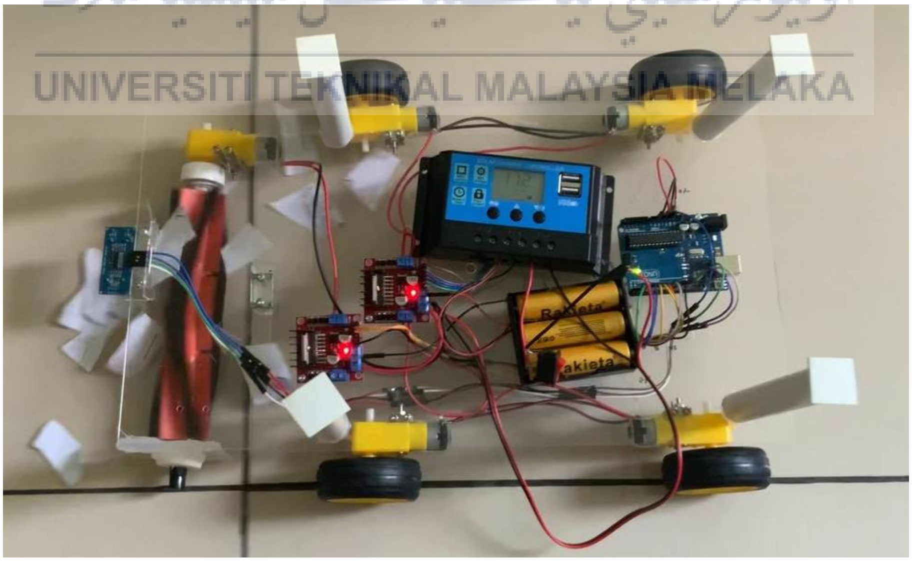

Figure 4.7 The paper scraps is placed in front of the robot.

Figure 4.7 shows the.paper scraps is placed in front of the robot while the robot is ready to start cleaning process.

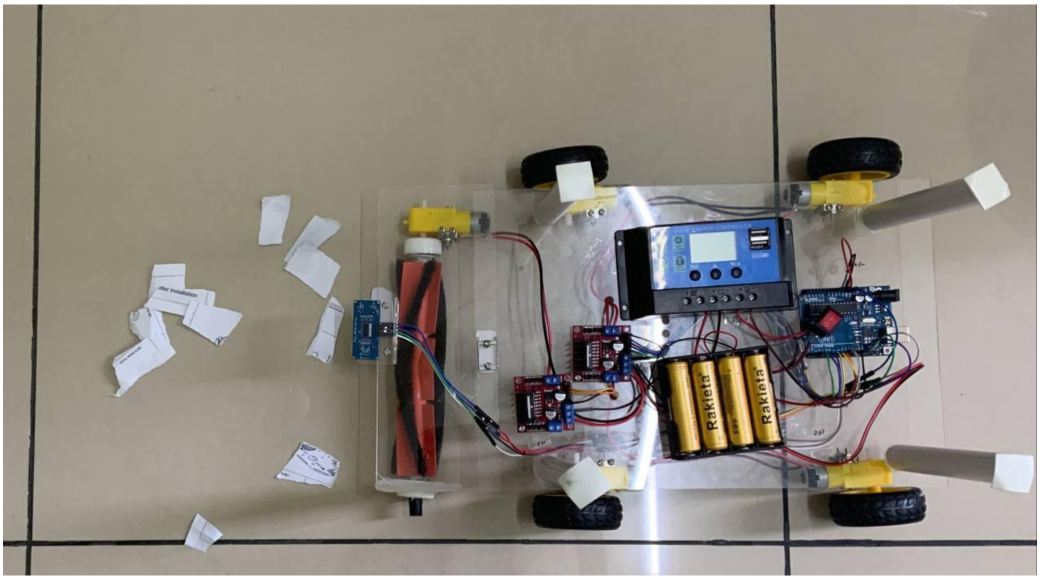

Figure 4.8 The robot starts the cleaning process by rotating the brush.

Figure 4.8 shows the.robot starts the cleaning process by rotating the brush and moving in a straight line. The paper scraps were sweeped away instead of left behind of the robot.

4.2.4 Testing for ultrasonic sensor to detect roof edge

Figure 4.9 The robot is at the static state and ready to move in a straight line.

Figure 4.9 shows the robot is at the static state and ready to move in a straight line to test whether if it stops when reaching the edge of the surface.

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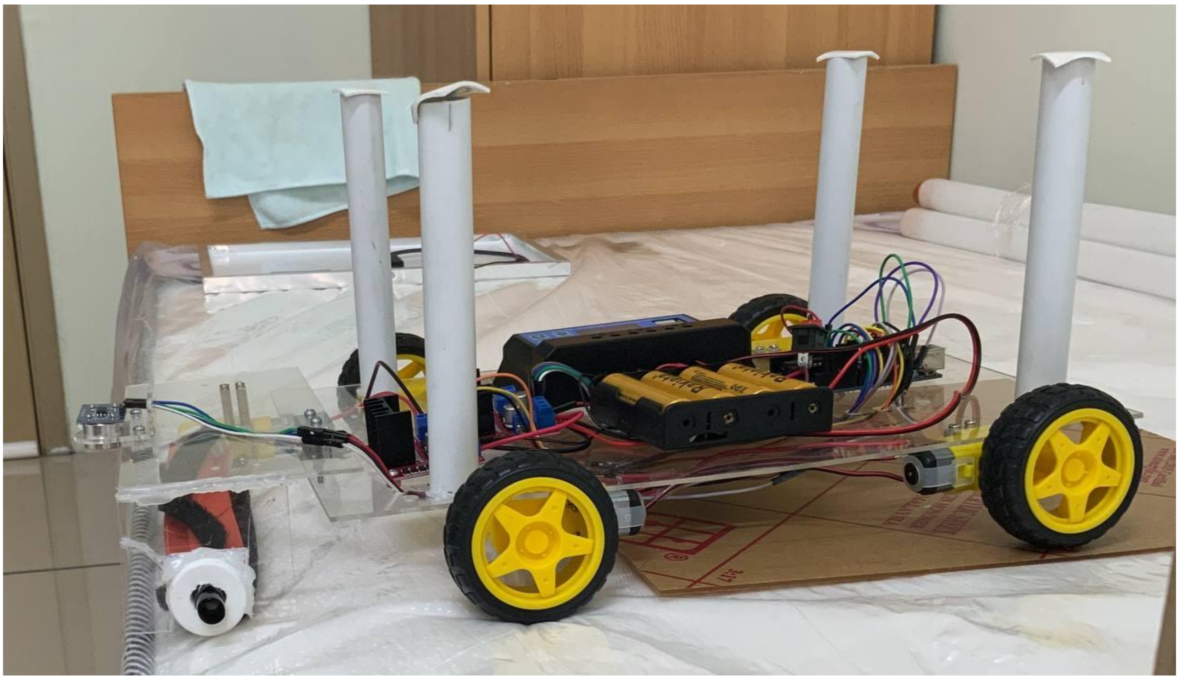

Figure 4.10 The robot stops at the edge of the surface.

Figure 4.10 shows the robot stops at the edge of the surface. However, the robot should stop immediately when the perpendicular distance between the ultrasonic sensor and the surface is more 6 cm. The robot stopped immediately to prevent falling from the high place.

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4.3 Analysis of performances of the robot

4.3.1 Testing of voltage and current used for robot moving straight in 5 seconds with load.

Figure 4.11 Initial voltage and current readings obtained from the robot with load.

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Figure 4.11 shows the.initial voltage and current readinsgs obtained from the robot with load attached. From the figure above, the initial voltage is 13.1 V while the initial current is 0.09 A.

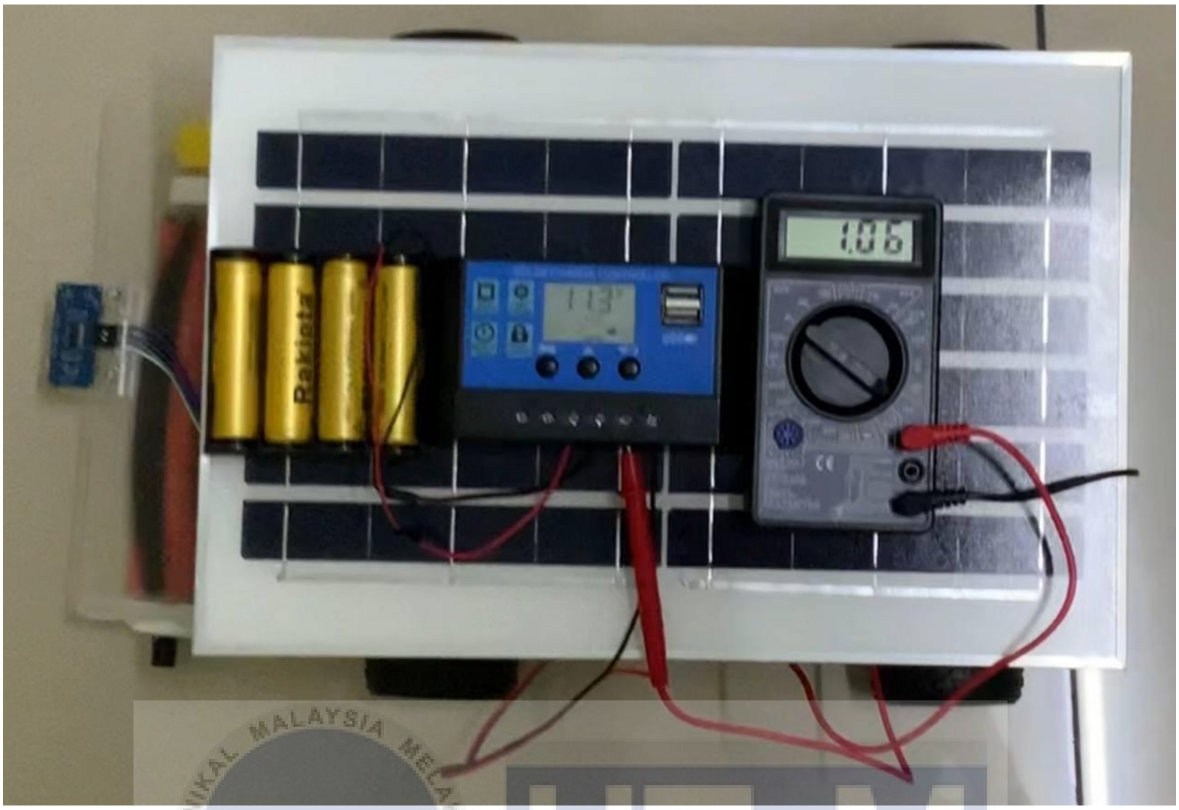

Figure 4.12 The readings of voltage and current obtained from the moving robot with load.

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Figure 4.12 shows the voltage and current readinsgs obtained from the moving robot with load attached. From the figure above, the voltage reading dropped to 11.3 V while the initial current increased to 1.06 A. When the circuit is connected, the current draw increases and this can lead to a voltage drop due to internal resistance in the power supply or the circut.

4.3.2 Testing of voltage and current used for robot moving straight in 5 seconds without load.

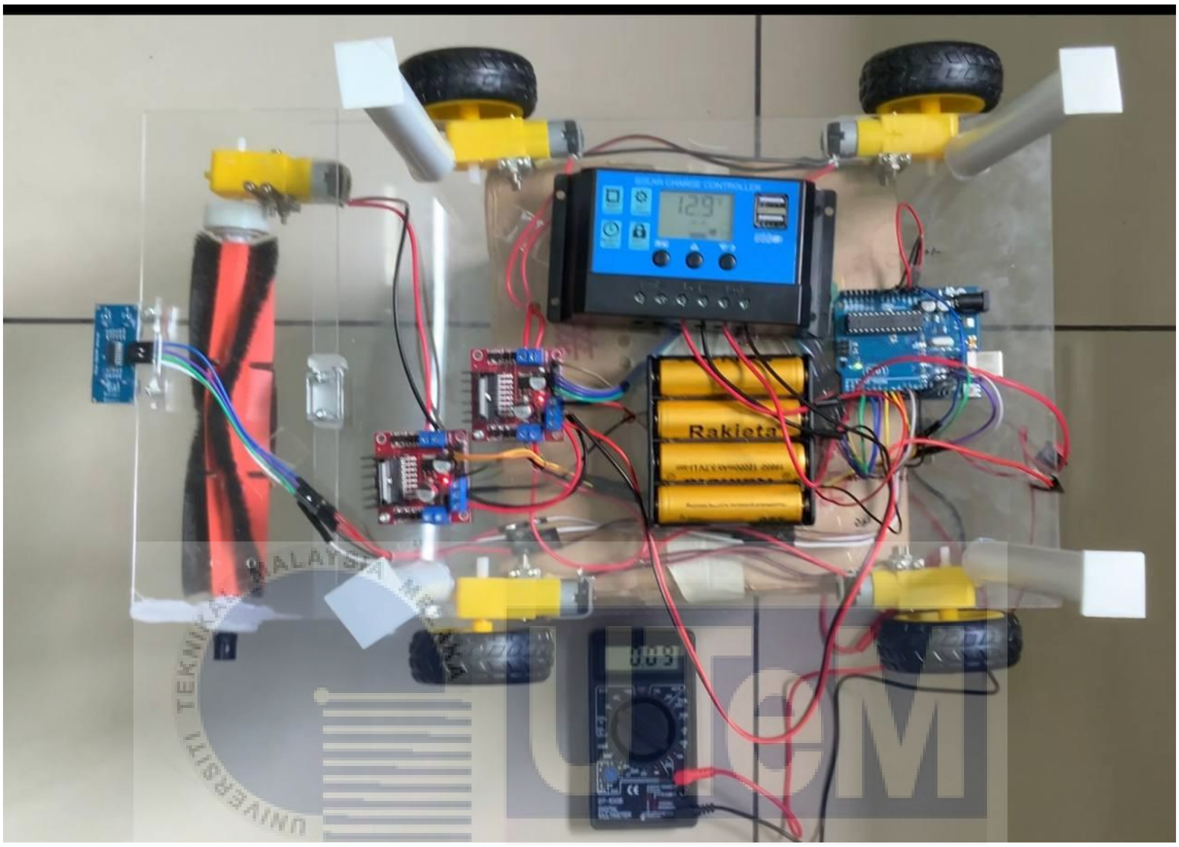

Figure 4.13 Initial voltage and current readings obtained from the robot without load

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Figure 4.13 shows that the.initial voltage and current readinsgs obtained from the robot without load attached. The robot without load attached indicates that the robot is functioning without affected by the weight of the load. In this case, the robot was lifted up from the ground in order to carry this testing. From the figure above, the initial voltage is 12.9 V while the initial current is 0.09 A.

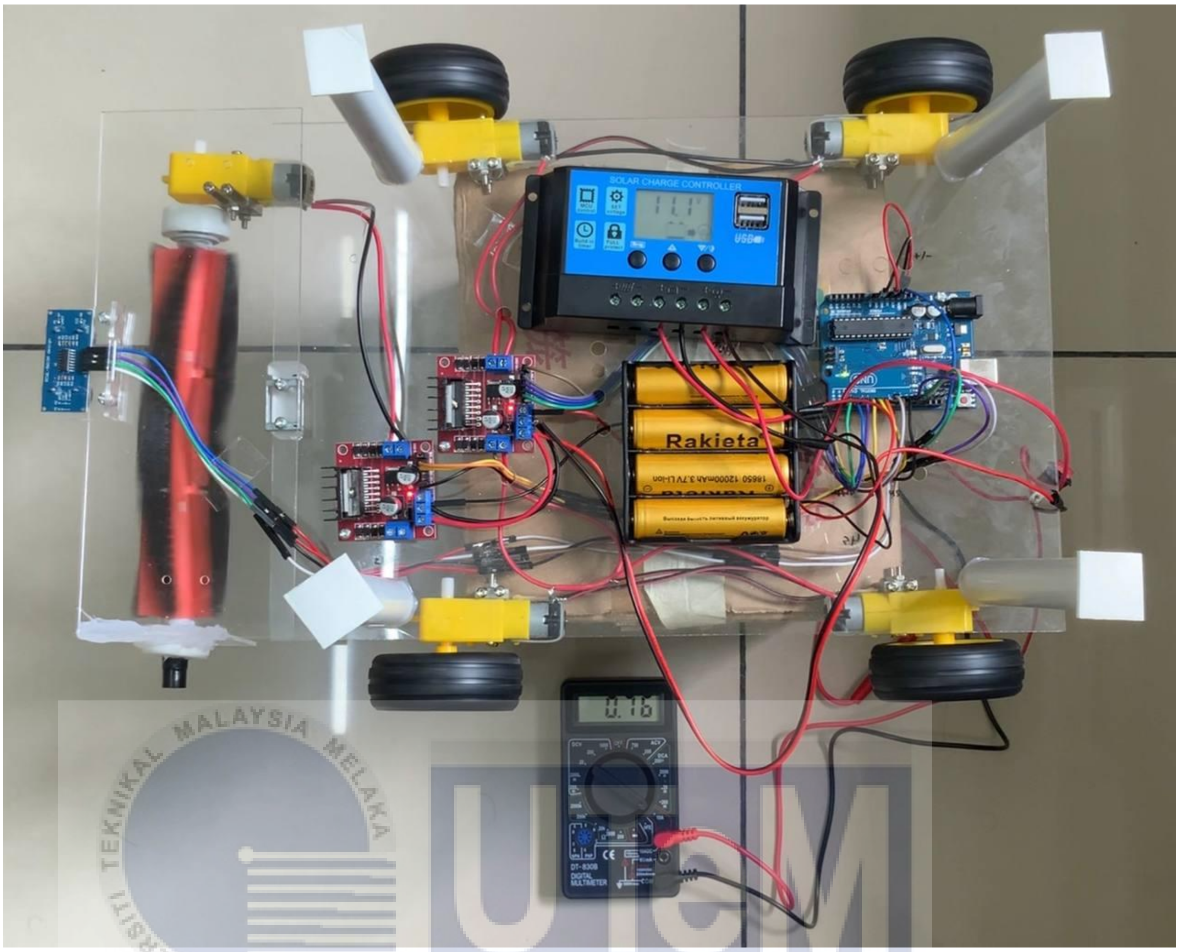

Figure 4.14 The readings of voltage and current obtained from the moving robot without load.

Figure 4.14 shows the voltage and current readinsgs obtained from the moving robot without load attached. From the figure above, the voltage reading dropped to 11.1 V while the initial current increased to 0.76 A. When the circuit is connected, the current draw increases and this can lead to a voltage drop due to internal resistance in the power supply or the circut.

4.3.3 Experiment data of voltage and current used by the robot

Table 4.1 Voltage and current used for robot moving straight in 5 seconds with load.

1st trial

Time (s)	0	1	2	3	4	5
Voltage (V)	13.1	11.3	10.7	10.7	10.7	12.5
Current (A)	0.09	1.06	0.96	0.94	0.95	0.09

2nd trial

Time (s)	0	1	2	3	4	5
Voltage (V)	12.8	12.8	10.9	10.9	10.8	12.7
Current (A)	0.09	0.89	0.96	0.95	0.95	0.09

3rd trial

Time (s)	0	1	2	3	4	5
Voltage (V)	12.9	11	11	10.9	10.8	12.5
Current (A)	0.09	1.01	1	0.96	0.95	0.09

4th trial

Time (s)	0	1	2	3	4	5
Voltage (V)	12.7	10.8	10.8	10.7	10.5	12.7
Current (A)	0.09	0.95	0.93	0.9	0.91	0.09

Average

Time (s)	0	1	2	3	4	5
Voltage (V)	12.875	11.475	10.85	10.8	10.7	12.6
Current (A)	0.09	0.9775	0.9625	0.9375	0.94	0.09

Table 4.1 shows that data recorded of voltage and current used for the robot moving straight in 5 seconds with load for 4 times experiment and the average data.

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Table 4.2 Voltage and current used for robot moving straight in 5 seconds without load.

1st trial

Time (s)	0	1	2	3	4	5
Voltage (V)	12.9	11.5	11.3	11.1	11.1	12.5
Current (A)	0.09	0.81	0.79	0.76	0.78	0.09

2nd trial

Time (s)	0	1	2	3	4	5
Voltage (V)	12.6	10.9	11.1	11	11	12.2
Current (A)	0.09	0.88	0.77	0.74	0.78	0.09

3rd trial

Time (s)	0	1	2	3	4	5
Voltage (V)	12.6	11.3	11.1	11	10.8	12.2
Current (A)	0.09	0.84	0.73	0.72	0.72	0.09

4th trial

Time (s)	0	1	2	3	4	5
Voltage (V)	12.6	11.1	11	11	10.9	12
Current (A)	0.09	0.81	0.72	0.74	0.72	0.09

Average

Time (s)	0	1	2	3	4	5
Voltage (V)	12.675	11.2	11.125	11.025	10.95	12.225
Current (A)	0.09	0.835	0.7525	0.74	0.75	0.09

Table 4.2 shows that data recorded of voltage and current used for the robot moving straight in 5 seconds without load for 4 times experiment and the average data.

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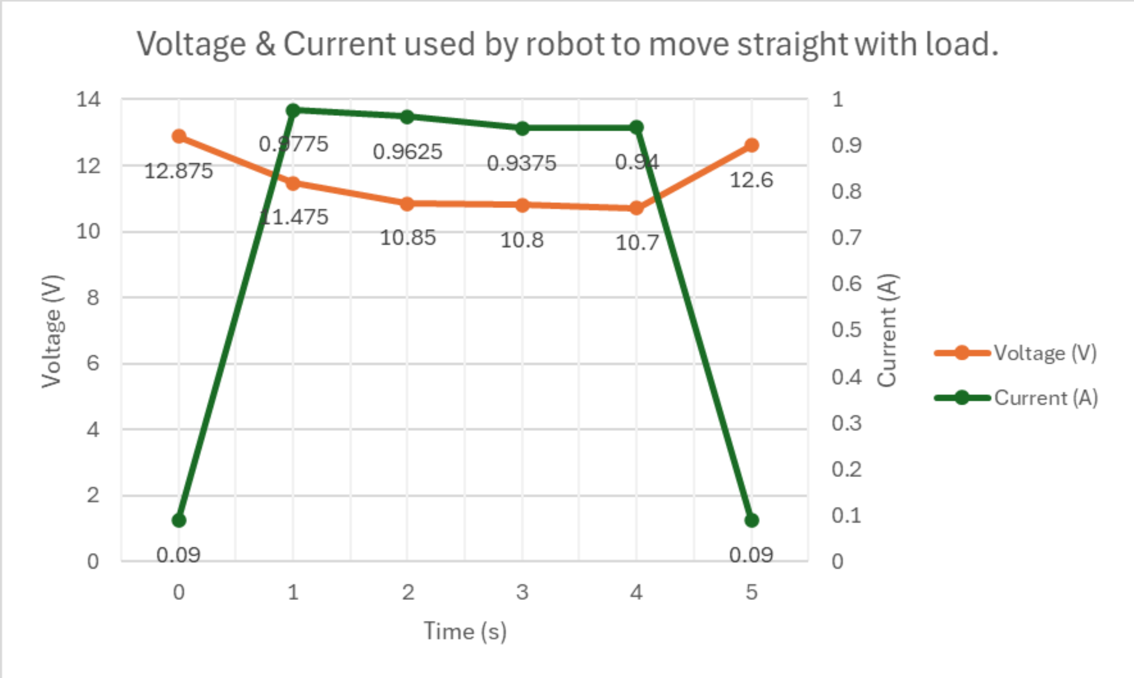

Figure 4.15 **Voltage and current used by robot to move straight in 5 secondswith load.**

Figure 4.15 shows the graph of voltage and current readinsgs obtained from the moving robot in 5 seconds with load attached. From the figure above, the voltage reading dropped from 12.875 V to 10.7 V before it returned back to 12.6 V at the 5-second. The reading of current increased from 0.09 A to the peak of 0.9775 A in the first second. Then, the current used by the robot maintained in average of 0.954 A before it stopped at the 5-second. This indicates that when the circuit is connected, the current draw increases and this can lead to a voltage drop due to internal resistance in the power supply or the circut. When the cicuit is switched off, the current draw decreases and the voltage tends to recover to its original value.

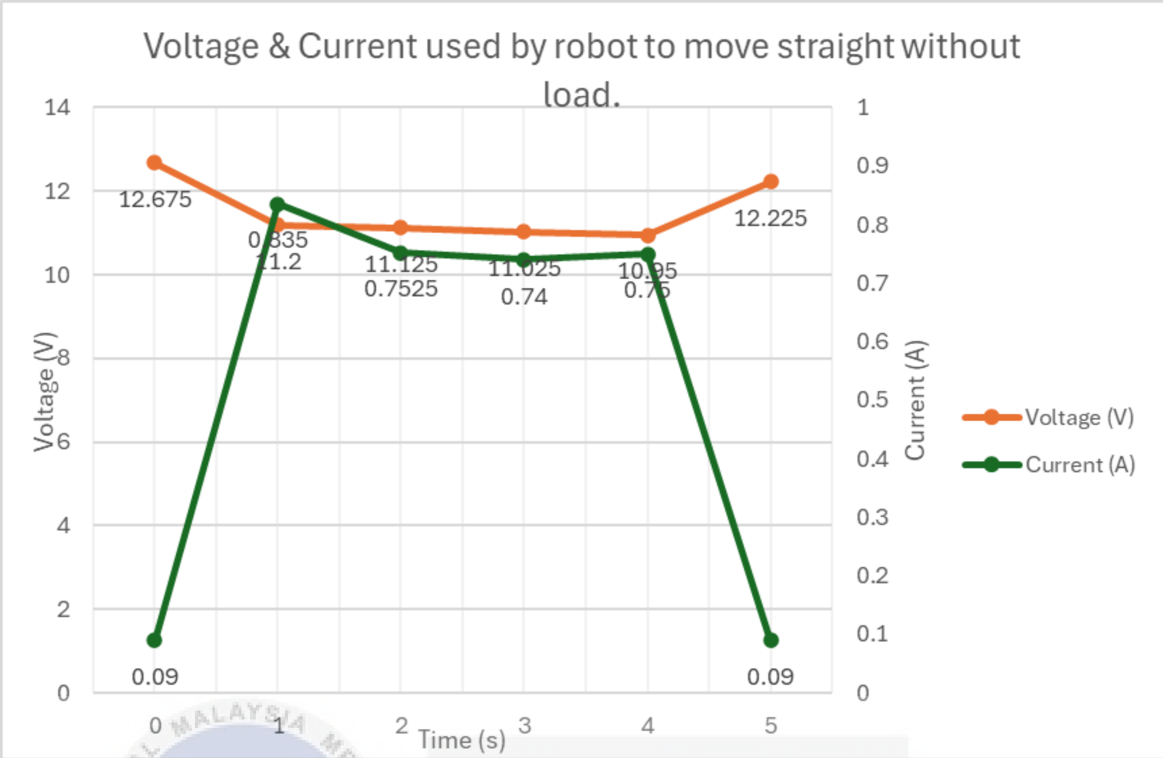

Figure 4.16 Voltage and current used by robot to move straight line in 5 seconds without load.

Figure 4.16 shows the graph of voltage and current readinsgs obtained from the moving robot in 5 seconds without load attached. From the figure above, the voltage reading dropped from 12.675 V to 10.95 V before it returned back to 12.225 V at the 5-second. The reading of current increased from 0.09 A to the peak of 0.835 A in the first second. Then, the current used by the robot maintained in around 0.769 A before it stopped at the 5-second. This indicates that when the circuit is connected, the current draw increases and this can lead to a voltage drop due to internal resistance in the power supply or the circut. When the cicuit is switched off, the current draw decreases and the voltage tends to recover to its original value.

Table 4.3 Power consumptions of the robot moving straight in 5 seconds with and without load.

Time (s)	0	1	2	3	4	5
Power (W), with load	1.15875	11.21681	10.44313	10.125	10.058	1.134
Power (W), without load	1.14075	9.352	8.371563	8.1585	8.2125	1.10025

Table 4.3 shows the table of power consumptions of the robot moving straight in 5 seconds with and without load. The power consumptions were calculated by using formula $P = IV$ where the P is the power, I is the current and V is the voltage. Both current and voltage are obtained from the average voltage and current in Table 4.1 and Table 4.2.

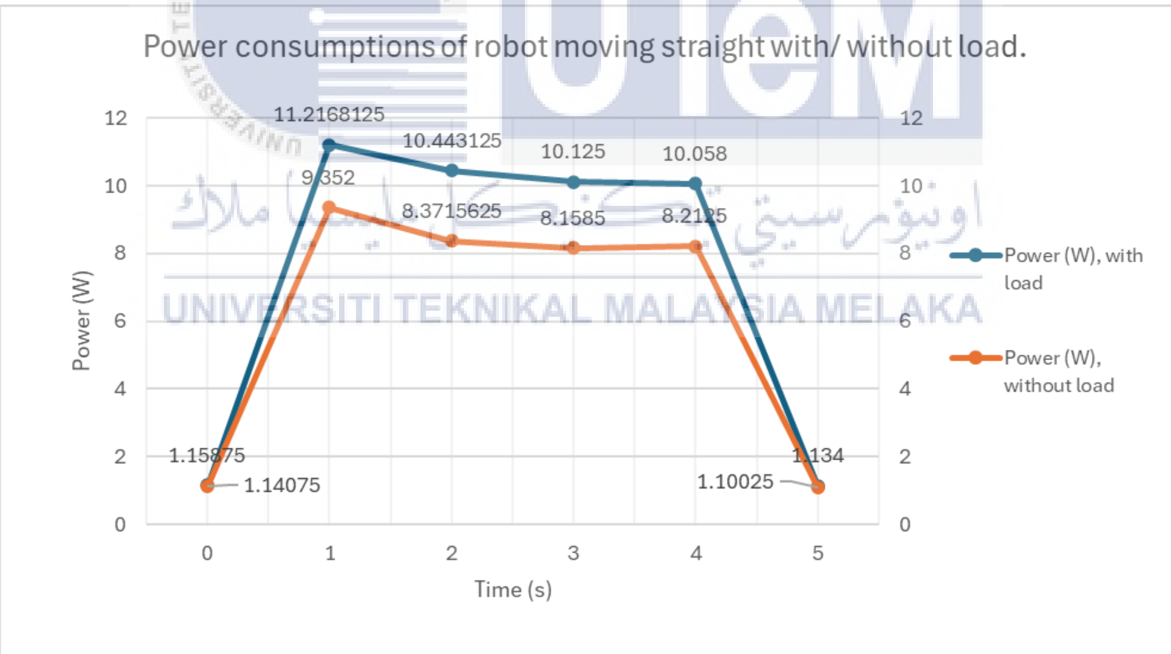

Figure 4.17 Power consumptions of the robot moving straight in 5 seconds with and without load.

Figure 4.17 shows the graph of power consumptions of the robot moving straight in 5 seconds with and without load. Based on the graph, the power consumptions of robot moving straight without load is lower than the robot moving straight with load.

4.3.4 Estimation of batteries runtime

The estimation of battery runtime can be calculated using the formula:

$$Battery\ runtime\ (hours) = \frac{Battery\ Capacity\ (Ah)}{Current\ drawn\ (A)} \quad \textbf{(1)}$$

In this project, based on the equation (1), the batteries with a total capacity of 48 ampere-hours (Ah) and estimated current drawn of 0.954 A and 0.769 A for with and without load respectively during the robot moving duration. Hence, the battery runtimes are 50.3 hours and 62.4 hours for the robot operating with load and without load respectively. By analyzing the battery performance both with and without load allows for a comprehensive evaluation of the battery's characteristics. In this case, the load mainly comes from the weight of robot, the users can choose to remove the solar panel while using the robot if they need for the longer runtime of robot. Therefore, the analysis of the battery runtime without load is generally an idle situation for robot operating. This helps to understand the behaviour of the robot in designing the system.

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4.3.5 Estimation of charging time of solar panel

Figure 4.18 Measure the output voltage (V) and current (A) of the solar panel

Figure 4.18 shows the measurement of the output voltage and current of the solar panel. The solar panel used in this project has the maximum output voltage of 7 V and output current of 1.82 A. Based on the maximum output current generated by the solar panel, the estimation charging time can be calculated by the following formula:

$$Charging\ Time\ (hours) = \frac{Battery\ Capacity\ (Ah)}{Solar\ panel\ output\ current\ (A)} \tag{2}$$

In this project, based on the equation (2), the batteries with the total capacity of 48 ampere-hour (Ah) and the estimated maximum solar panel output current of 1.82 A. Hence, the estimation of charging time is 26.4 hours. This charging time is estimated in idle case which is the maximum amount of sunlight received by the solar panel. This is due to the current generated by the solar panel depends on the intensity of the sunlight.

4.4 Summary

The system of the robot is done by programmed the Arduino board with the external hardware such as motor drivers, motors, brush, batteries, and the solar panel. Based on the hardware connection shown in Figure 4.1, the robot is successfully desgined for the purpose of solar panel roof cleaning. From Figure 4.6, Figure 4.8, and Figure 4.10, the robot is done developing to carry out the operations such as moving in a straight line, stopping, rotating the brush to clean the paper scraps and roof edge detection. The experiments show the Arduino microcontoller successfully manages the robot'movements, sensors and cleaning operation. The robot has the batteries capacity of 48 ampere-hours (Ah) and can operate for 50.3 hours and 62.4 hours for with load and without load operating hours respectively. The estimation of charging time is 26.4 hours to fully charge the 48 Ah batteries with the maximum solar panel output current of 1.82 A.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the obejctives of the project have been successfuly achieved. The implementation of the system demonstrated effective control of the four-wheeled robot using a single motor driver and the brush cleaning mechanism. The Arduino program code provided the accurate motor control which allows the robot to move forward and stop immediately when reaching the edge of the roof. Moreover, the analysis of the voltage, current and power consumptions provided the valuable insights into the performance of the system.

Overall, the project met the goals of creating a functional cleaning robot. The solar panel cleaning robot in this project utilizes an Arduino-based system to automate the cleaning process of solar panels. The project incorporates various components, including an Arduino board, ultrasonic sensor, motor driver, rechargeable battery and the solar panel. The robot's functionality involves detecting roof edge using the ultrasonic sensor, controlling the motors for movement and rotation, and utilizing a brush to clean the solar panels. After completing all the planned procedures of this project, the project gave an expected results. All of the hardware work well according to their functions which are the ability of distance measurement, movement control of the robot and the cleaning process. The ultrasonic sensor are able to measure the distance from the robot to the edge of cleaning surface. This provides the signal to Arduino board that will affect the movement of the robot. Hence, the robot were successfully stopping if the perpendicular distance measured between the sensor and the surface was more than 6cm. Otherwise, the robot keeps moving and cleaning the solar panel.

5.2 Recommendations

Some potential future enhancements to this solar panel cleaning robot include:

- Using Raspberry Pi as the microcontroller of this project to have more powerful computing ability which able to provide multiple features for the robot [19].
- Using apps as interface to display the status of the robot and control the movement of the robot.
- Implement more cleaning techniques such as dry-cleaning techniques, water-based cleaning techniques etc. so that the robot can provide solar panels cleaning process for various environments such as desert.
- Improve the structure design of the robot so that the robot can have a suitable weight and arrangement of components to overcome the different type of situations such as climbing up roofs with angles, turning operations for larger size of cleaning area etc.

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5.3 Potential for Commercialization

Solar-powered cleaning robot for solar panel roof cleaning process has significant potential for commercialization, particularly as the increase for climate change issues and environment pollution issues. There is a large space for emerging and development of solar energy which is renewable energy in future [20]. Since people nowadays are very concerned about solar energy, solar panel installation companies can take the chance to incorporate the solar panel cleaning robot as part of their service offerings. By offering an automated cleaning solution, these companies can enhance the maintenance and performance of the solar panels they install for their customers. The robot can be offered as an additional service or bundled with solar panel installations. By targeting the growing of solar energy market and emphasizing the pros of automation, efficiency and sustainability, this project has the potential for commercialization and contribution to solar panel maintenance technology.

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APPENDICES

Appendix A Arduino sketch Source Code

Arduino IDE Source Code

```
// Motor driver connections
const int motorA1 = 2; // Motor A input 1
const int motorA2 = 3; // Motor A input 2
const int motorB1 = 4; // Motor B input 1
const int motorB2 = 5; // Motor B input 2
const int motorC1 = 6; // Motor C input 1
const int motorC2 = 7; // Motor C input 2

// Motor speed control pins
const int enA = 9;      // Motor A speed control
const int enB = 10;     // Motor B speed control
const int enC = 11;     // Motor of brush speed control

// Ultrasonic sensor pins
const int trigPinFront = 12; // Trig pin of front-facing Ultrasonic Sensor
const int echoPinFront = 13; // Echo pin of front-facing Ultrasonic Sensor

void setup() {
  // Set the motor control pins as outputs
  pinMode(motorA1, OUTPUT);
  pinMode(motorA2, OUTPUT);
  pinMode(motorB1, OUTPUT);
  pinMode(motorB2, OUTPUT);
  pinMode(motorC1, OUTPUT);
  pinMode(motorC2, OUTPUT);

  // Set the motor speed control pins as outputs
  pinMode(enA, OUTPUT);
  pinMode(enB, OUTPUT);
  pinMode(enC, OUTPUT);

  // Set ultrasonic sensor pins
  pinMode(trigPinFront, OUTPUT);
  pinMode(echoPinFront, INPUT);
}

void loop() {
```

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```
// Move forward if there are no roof edge in front
  if (! isObstacleDetectedFront()) {
    moveForward(60, 70); // Speed values range from 0 to 255

  } else {
    // Stop if an roof edge is detected in front
    stopMotors();
    delay(5000);

  }
}

// Function to move forward
void moveForward(int speedAB, int speedC) {
  analogWrite(enA, speedAB);
  analogWrite(enB, speedAB);
  analogWrite(enC, speedC);

  digitalWrite(motorA1, HIGH);
  digitalWrite(motorA2, LOW);
  digitalWrite(motorB1, LOW);
  digitalWrite(motorB2, HIGH);
  digitalWrite(motorC1, LOW);
  digitalWrite(motorC2, HIGH);
}

// Function to stop motors
void stopMotors() {

  analogWrite(enA, 0);  // Set speed to 0 for motor A
  analogWrite(enB, 0);  // Set speed to 0 for motor B

  digitalWrite(motorA1, LOW);
  digitalWrite(motorA2, LOW);
  digitalWrite(motorB1, LOW);
  digitalWrite(motorB2, LOW);
  digitalWrite(motorC1, LOW);
  digitalWrite(motorC2, LOW);
}

// Function to check if an obstacle is detected in front
bool isObstacleDetectedFront() {
  return getDistance(trigPinFront, echoPinFront) > 6;
}

// Function to get distance from an ultrasonic sensor
```

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```
int getDistance(int trigPin, int echoPin) {
  // Trigger the ultrasonic sensor
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  // Read the echo pulse duration
  int duration = pulseIn(echoPin, HIGH);

  // Calculate distance in centimeters
  return duration * 0.034 / 2;
}
```

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Appendix B Gantt Chart of Project Planning

BDP 1 – Gantt Chart

Tasks	Project Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PSM 1 Briefing by JK PSM, FTKEE														
Determine PSM Title														
MODULE 1: INTRODUCTION														
Study on Project Background, Problem Statement, Project Objectives and Project Scope														
MODULE 2: LITERATURE REVIEW														
Research on related Global and Society Issues														
Research on Hardware and Software components														
Progress Work 1: Logbook Submission														
Research on Previous Projects														
CHAPTER 3: METHODOLOGY														
Research on Design and Development of Project														
Research on Cost and Budget of Project														
Unit Testing, Integrated Circuit Testing in Simulation														
First Draft Report														
Progress Work 2: Logbook Submission														
Correction for Project Report and Mock Presentation														
Presentation and Report Submission														

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BDP 2 – Gantt Chart

Tasks	Project Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Purchase Components and Materials														
Development of Hardware design														
Development of Software design														
First Testing of Prototype														
Progress Work 1: Logbook Submission														
Testing of brush cleaning mechanism														
Integrating wheels and brush cleaning mechanism														
Create the body chasis of the robot														
Assemble all the compenents and circuit on the body chassis														
Progress Work 2: Logbook Submission														
Whole System Testing														
Analysis the performance of the robot														
Update the report														
Create the Poster														
Presentation and Report Submission														

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