Mechatronics Engineering
(MTE) Program

Faculty of Engineering
Mansoura University

Project 1

Autonomous Solar Panels Cleaning Robot

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Abstract

Recent achievement and progress in solar PV play a significant role in controlling climate change therefore it's valuable to enhance and improve its efficiency. The efficiency of solar energy produced by photovoltaic modules can be affected by two main factors: environmental - such as humidity, wind speed, precipitation, and temperature - and non-environmental, which takes into account factors such as atmospheric pollution, dust accumulation, and bird droppings. Dust accumulation, dirt, and bird dropping are some leading causes that lead to the poor functionality of solar panels. [1] The dust particles accumulating on the solar panels will prevent the solar energy from reaching the solar cells, thereby reducing the overall power generation. Power output is reduced as much as by 50%, if the module is not cleaned for a month. In order to regularly clean the dust, an automatic cleaning robot which removes the dust on the solar panel is developed. [2]

In desert zones, a continuous cleaning activity of photovoltaic panels in solar plants is required since the deposition of both airborne dust and sand after a storm can reduce their efficiency up to 80%. Manual cleaning of the photovoltaic panels in dry areas is costly, cannot make use of water and workers must be employed several times in a month, often under extreme environmental conditions. For all these reasons, the research of cleaning solutions performed by autonomous robotic systems are seen beneficial to recover the solar panels efficiency at reasonable costs also nightly. In this respect, a robot cleaning device is developed and it travels the entire length of the panel. Arduino Uno microcontroller is used to implement robots control system. A mobile app is used to setup the robot and give the user the best experience. The robot works autonomously every day to improve solar panel efficiency by 10%-30% at the day time. Because of its design the device is suitable for both solar farms and solar roofs. [3]

The objective of this project was to design a solar panels cleaning robot that increase the power generation of the solar panel. The robot is used to remove the dust, dirt and snow deposited on the solar panel thus helping the solar panel to absorb the maximum quantity of energy.

Acknowledgements

The success and final outcome of this project required a lot of guidance and assistance from many people and we are extremely privileged to have these all along our way to complete our project. All that we have done is only due to such supervision and assistance, and we won't forget to thank them.

We would like to express our thanks and deepest appreciation to our project supervisor Dr. Fatma Elerian who didn't keep any effort in encouraging us to do such a great job.

Last but not least, we are very thankful to our der parents for their continuous support at all the time in order to see this moment of our first project on the university, we always wish you happiness and loge life.

Table of Contents

List of Symbols

Symbol	Definition	Unit
W	Weight	Newton, N
W_x	Weight on X-axis direction	Newton, N
W_y	Weight on Y-axis direction	Newton, N
N_w	Reaction force between wheels and surface	Newton, N
F	Force	Newton, N
M	Moment	Newton-metre, Nm
E	Supply voltage	Volts, V
I	Supply current	Ampere, I
T	Torque	Newton-metre, Nm
Ω	Rotational speed	Revolution per minute, rpm
Kω	Motor velocity constant	Volts per kilorevolution per minute, V/krpm
Kt	Motor torque constant	Newton metres per ampere, N·m/A
R	Arm moment	Newton-metre, Nm
Emf	Electromotive force	Volts, V
Eb	Voltage	Volts, V

List of Figures

List of Tables

Phase 1: Project Definition

1.1 Introduction

The sources of energy are classified into two variety, conventional energy and non-conventional energy resources. The conventional energy sources are depleting rapidly. This leads the world towards the growth, development, and usage of renewable energy sources. So, the new era of energy resources started, where friendly to the environment and sustainable in nature were mandatory.

Therefore, solar energy was accepted and tested by people as shown in (**FIGURE 1**), as this could fulfils all the requirements and demands. Once solar panels are eructated on rooftop, it starts to generate power without any pollution with natural sun light. It generates electricity with fixed structure without any noise, so lifetime of the plant increased. It can be installed anyplace and any capacity range with short duration of time. The main objective of this project is to utilize the solar radiation properly by maintaining the PV panels always clean.

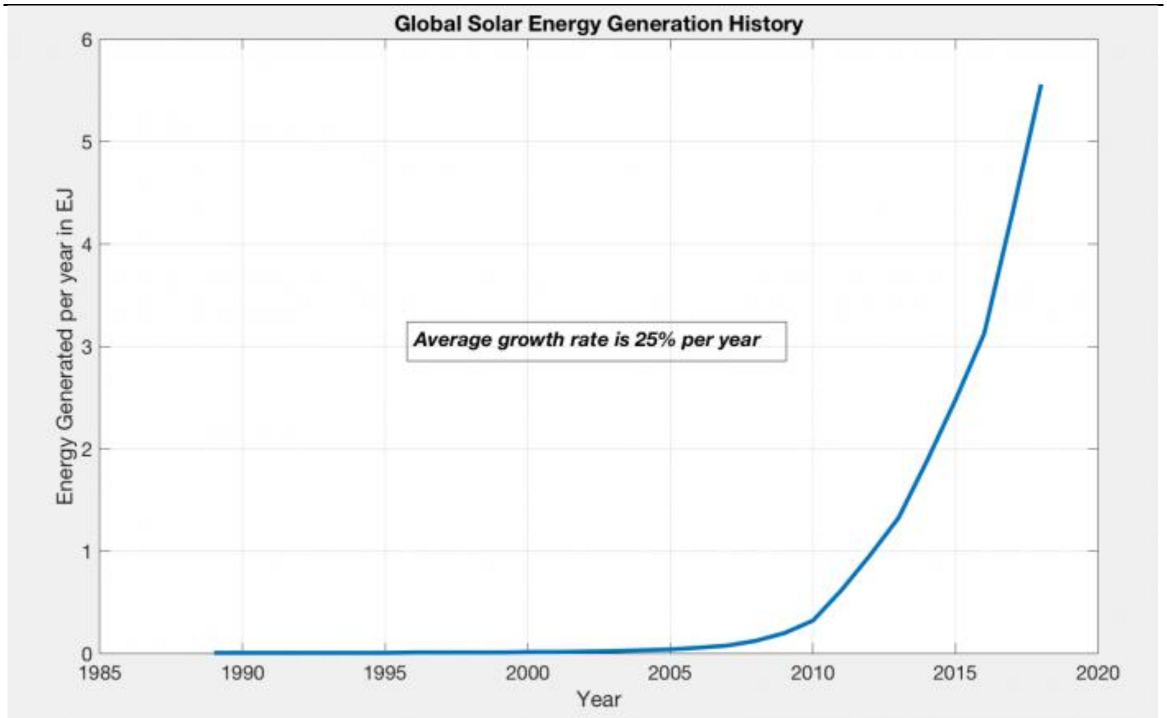


FIGURE 1

The history of global solar energy generation in Exajoules (EJ) of energy each year (1 EJ = 1018J). [6]

The dust and dirt dropping on the panel decreases the light fall over the panel, due to this the efficiency of the PV system decreased even during good solar radiation, see (**FIGURE 2**). This problem is common for a large scale to small domestic rooftop system. In case of small rooftop system, manual cleaning is easy and possible. But in case of large-scale cleaning, like MW PV power plants, more manpower required and manual cleaning consume more time also difficult to clean entire panels at a time. Automated panel washing is a great investment because manual washing desert areas is inefficient. We built an automated cleaning robot in this project.

Dust is a general term for any particulate matter less than 500 μm in diameter, which is about the dimension of an optical fiber used for communications or 10-times the diameter of a human hair. Dust can comprise small amounts of pollen (vegetation, fungi, bacteria), human/animal cells, hair, carpet and textile fibers (sometimes termed microfibers), and, most commonly, organic minerals from geomorphic fallout such as sand, clay, or eroded limestone [4]. Atmospheric dust (aerosols) is attributed to various sources, such as soil elements lifted by the wind (aeolian dust) volcanic eruptions, vehicle movement, and pollution. The particle size, constituents, and shape of the dust vary from region to region throughout the world. Furthermore, the deposition behavior and accumulation rates can vary dramatically in different localities. These factors are based on the geography, climate, and urbanization of a region. Important dust characteristics are typically size and distribution, density, shape, composition and chemistry, and charge. Important ambient conditions that relate to these characteristics are humidity/moisture, gradients, wind velocity (variation in direction, speed), and time variations. [5]

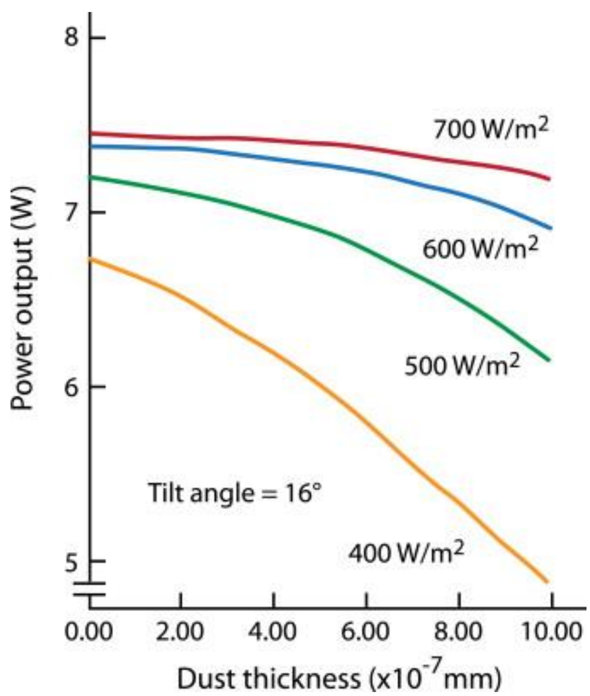


FIGURE 2

PV module power degradation for various solar intensities as a function of dust thickness [7]

1.1.1 Renewable Energy

Renewable energy is energy from sources that are naturally replenishing but flow-limited; renewable resources are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time.[8]

The major types of renewable energy sources are:

- Biomass
    - Wood and wood waste
    - Municipal solid waste
    - Landfill gas and biogas
    - Biofuels
- Hydropower
- Geothermal
- Wind
- Solar

1.1.2 *Solar Energy*

Radiation from the Sun capable of producing heat, causing chemical reactions, or generating electricity. The total amount of solar energy incident on Earth is vastly in excess of the world's current and anticipated energy requirements. If suitably harnessed, this highly diffused source has the potential to satisfy all future energy needs. In the 21st century solar energy is expected to become increasingly attractive as a renewable energy source because of its inexhaustible supply and its nonpolluting character, in stark contrast to the finite fossil fuels coal, petroleum, and natural gas.

The Sun is an extremely powerful energy source, and sunlight is by far the largest source of energy received by Earth, but its intensity at Earth's surface is actually quite low. This is essentially because of the enormous radial spreading of radiation from the distant Sun. A relatively minor additional loss is due to Earth's atmosphere and clouds, which absorb or scatter as much as 54 percent of the incoming sunlight. The sunlight that reaches the ground consists of nearly 50 percent visible light, 45 percent infrared radiation, and smaller amounts of ultraviolet and other forms of electromagnetic radiation.

The potential for solar energy is enormous, since about 200,000 times the world's total daily electric-generating capacity is received by Earth every day in the form of solar energy, see (**FIGURE 3**). Unfortunately, though solar energy itself is free, the high cost of its collection, conversion, and storage still limits its exploitation in many places. Solar radiation can be converted either into thermal energy (heat) or into electrical energy, though the former is easier to accomplish.

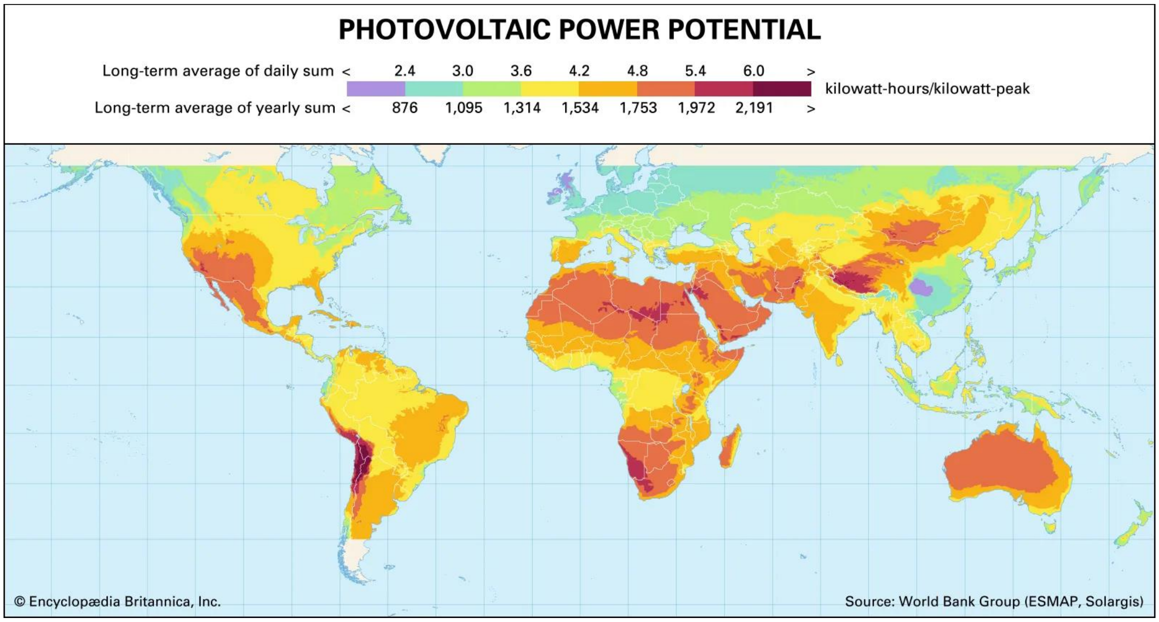


FIGURE 3

Earth's solar energy potential. [9]

There are three main ways to harness solar energy: photovoltaics, solar heating & cooling, and concentrating solar power.

1.1.3. Photovoltaics (PV)

Photovoltaic (PV) devices generate electricity directly from sunlight via an electronic process that occurs naturally in certain types of material, called semiconductors. Electrons in these materials are freed by solar energy and can be induced to travel through an electrical circuit, powering electrical devices or sending electricity to the grid. [10]

PV devices can be used to power anything from small electronics such as calculators and road signs up to homes and large commercial businesses.

1.1.4. Types of PV Cells

Photovoltaic cell can be manufactured in a variety of ways and from many different materials. The most common material for commercial solar cell construction is Silicon (Si), but others include Gallium Arsenide (GaAs), Cadmium Telluride (CdTe) and Copper Indium Gallium Selenide (CIGS). Solar cells can be constructed from brittle crystalline structures (Si, GaAs) or as flexible thin-film cells (Si, CdTe, CIGS). Crystalline solar cells can be further classified into two categories—*monocrystalline* and *polycrystalline*, as shown in figure 4. As the names suggest, monocrystalline PV cells are comprised of a uniform or single crystal lattice, whereas polycrystalline cells contain different or varied crystal structures. Solar cells can also be classified by their number of layers or "p-n junctions". Most commercial PV cells are only single-junction, but multi-junction PV cells have also been developed which provide higher efficiencies at a greater cost. [11]

1.1.5. How does PV technology work?

Photons strike and ionize semiconductor material on the solar panel, causing outer electrons to break free of their atomic bonds. Due to the semiconductor structure, the electrons are forced in one direction creating a flow of electrical current. Solar cells are not 100% efficient in crystalline silicon solar cells, in part because only certain light within the spectrum can be absorbed. Some of the light spectrum is reflected, some is too weak to create electricity (infrared) and some (ultraviolet) creates heat energy instead of electricity, see (**FIGURE 4**). [12]

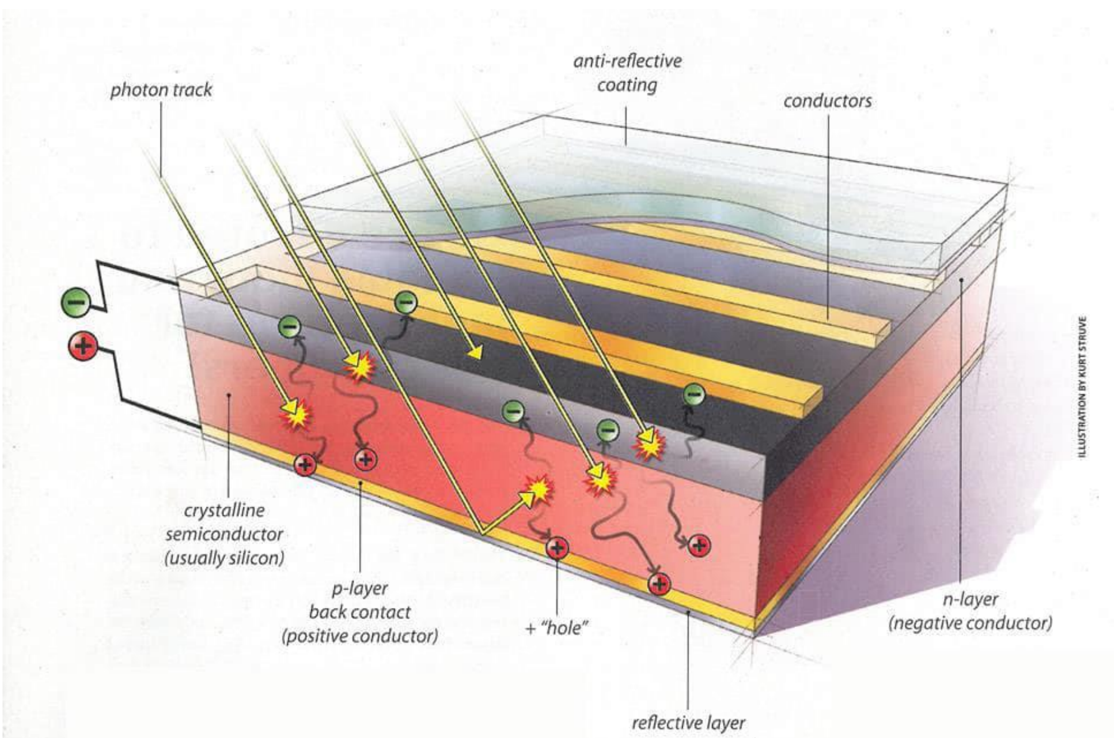


FIGURE 4

Diagram of a typical crystalline silicon solar cell. To make this type of cell, wafers of high-purity silicon are "doped" with various impurities and fused together. The resulting structure creates a pathway for electrical current within and between the solar cells. [13]

1.1.6. Solar Cell Efficiency

Efficiency is a design concern for photovoltaic cells, as there are many factors that limit their efficiency. The main factor is that 1/4 of the solar energy to the Earth cannot be converted into electricity by a silicon semiconductor. The physics of semiconductors requires a minimum photon energy to remove an electron from a crystal structure, known as the band-gap energy. If a photon has less energy than the band-gap, the photon gets absorbed as thermal energy. For silicon, the band-gap energy is 1.12 electron volts.[6] Since the energy in the photons from the sun cover a wide range of energies, some of the incoming energy from the Sun does not have enough energy to knock off an electron in a silicon PV cell. Even from the light that can be absorbed, there is still a problem. Any energy above the band-gap energy will be transformed into heat. This also cuts the efficiency because that heat energy is not being used for any useful task.[6] Of the electrons that are made available, not all of them will actually make it to the metal contact and generate electricity. Some electrons will not be accelerated sufficiently by the voltage inside the semiconductor to leave the system. These effects combine to create a theoretical efficiency of silicon PV cells is about 33%. [14]

$$\textit{efficiency} = \frac{\textit{panel power (in kW)}}{\textit{panel length} \times \textit{panel width (in m)}} \times 100\%$$

There are ways to improve the efficiency of PV cells, all of which come with an increased cost. Some of these methods include increasing the purity of the semiconductor, using a more efficient semiconducting material such as Gallium Arsenide, by adding additional layers or p-n junctions to the cell, or by concentrating the Sun's energy using concentrated photovoltaics. On the other hand, PV cells will also degrade, outputting less energy over time, due to a variety of factors including UV exposure and weather cycles. A comprehensive report from the National Renewable Energy Laboratory (NREL) states that the median degradation rate is 0.5% per year. [15]

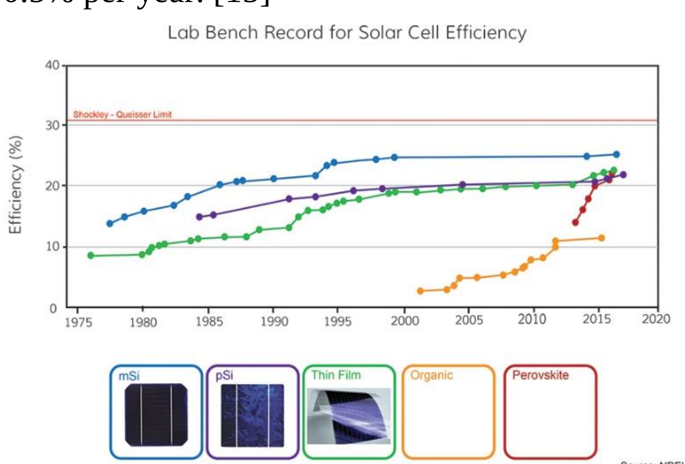


FIGURE 5

Lab bench record for solar cell efficiency [16]

1.2. Needs/Problems

Every project exists to fill a need or solve a problem, project needs/problems are the driving force of the project. Our project exists to help on solving the problems ***climate change*** and ***dust/dirt degradation of PV panels efficiency***, and to fill *world energy demeaned* which considers as a global need.

1.2.1. Climate Change

Climate change refers to long-term shifts in temperatures and weather patterns. These shifts may be natural, such as through variations in the solar cycle. But since the 1800s, human activities have been the main driver of climate change, primarily due to burning fossil fuels like coal, oil and gas. [17]

Burning fossil fuels for energy demands generates greenhouse gas emissions that act like a blanket wrapped around the Earth, trapping the sun’s heat and raising temperatures [18], see **FIGURE 6**.

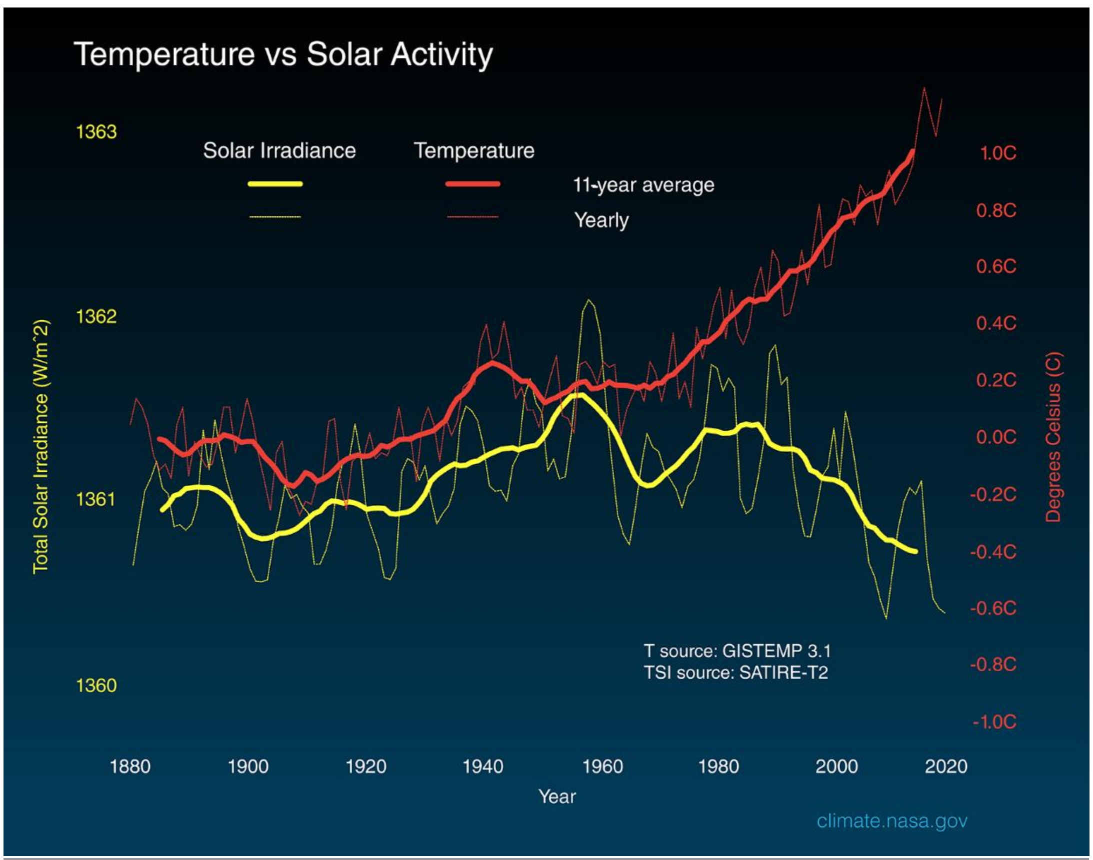


FIGURE 6

The graph compares global surface temperature changes (red line) and the Sun's energy that Earth receives (yellow line) in watts (units of energy) per square meter since 1880. [19]

Global climate change has already had observable effects on the environment. Glaciers have shrunk, ice on rivers and lakes is breaking up earlier, plant and animal ranges have shifted and trees are flowering sooner.

Effects that scientists had predicted in the past would result from global climate change are now occurring: loss of sea ice, accelerated sea level rise and longer, more intense heat waves.

Renewable energy tops the list of climate change solutions. That's because renewable energy sources such as solar and wind don't emit carbon dioxide and other greenhouse gases that contribute to global warming.

Since solar energy is one of the most important renewable energies, we have to ensure generating the most power from it.

1.2.2. Dust/Dirt degradation of PV Panels Efficiency

Experiments history:

Salim et al. (1988) found a 32% reduction in performance after eight months due to dust accumulation on a solar PV system in a village near Riyadh, Saudi Arabia (Chanchangi et al., 2020; Ndiaye et al., 2013).

Wakim et al. (1981) reported a 17% reduction in PV power due to the accumulation of sand on the panels in Kuwait City after six days.

Hussain et al. (2017) confirmed that the smaller particle blocks more sunlight and thus reduces the efficiency of solar panels. Also, they showed that in desert areas and due to dust accumulation the power efficiency of solar panels can be reduced up to 60%.

According to Mizanur et al. (2012) dust acts as a barrier between the solar panel and the sun's rays. Also, they found that the value of the short circuit current Isc of a clean panel is higher than the Isc of a dusty panel, and the power decreases with the amount of dust on the surface of panels.

According to Rao et al. (2014), the effect of dust on I-V characteristic of panels was studied. They observed that the deposit of dust did not significantly alter the open circuit voltage of PV systems. However, the dust deposits negatively affect the short-circuit current. Again, Rao et al. (2014) found that dust deposition leads to a decrease in generated power and an immense loss in energy produced and the economic loss of a PV power plant.

According to Sulaiman et al. (2011), the effect of the presence of dust was studied using artificial dust (mud and talcum), they found a reduction in a peak power generated up to 18% and they found that the differences between the results obtained using mud and talc were generally small (about 6%). They confirmed that a cleaning of the dust on the surface of the PV solar panel is necessary to ensure the best performance.

According to the study by Zeshan et al. (2017), the average output power was reduced up to 22% for June, 16% for July and 18% for August due to the accumulation of dust on the surface of the polycrystalline PV modules, exposed to the outdoor operating conditions in Pakistan. They concluded that a regular cleaning of the PV module is necessary to minimize efficiency losses.

According to the study by Prasanthi and Jayamadhuri (2015), a reduction of the peak power generated can be up to 30%, under higher irradiation, the effects of dust can be slightly reduced and not negligible. Also, they showed that the power can be improved by using cleaning. An increase in power up to 35% was found.

According to Sulaiman et al. (2014), the experiment was done by using a clean panel and a panel covered with talcum, dust, sand and moss. They showed that opaque particles tremendously affect the performance of solar PV.

According to Karmouch et al. (2017), the deposition and accumulation of airborne dust significantly reduces the efficiency of solar cells, by reducing the transmission of sunlight. They found approximately 10.4% reduction of efficiency after 16 weeks of exposure for 30° tilted panels and 9.7% for 55° tilted panels. They also recommended using a self-cleaning system product, especially in dusty areas with a low rainfall to prevent dust accumulation and to improve the energy performance module.

Recent Study of the influence of dust deposits on photovoltaic solar panels by Lasfar, S., Mouallif, I., Latrach, A., Chergui, M., Choukir, A., Diab, A. (2021) shows the following results:

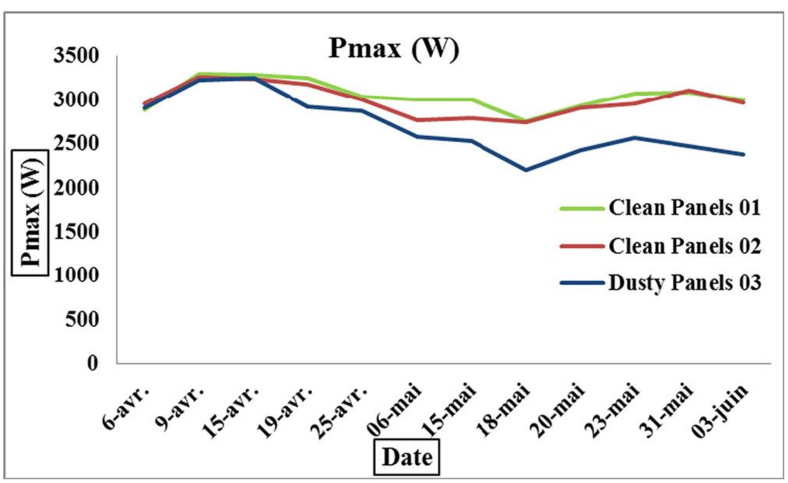
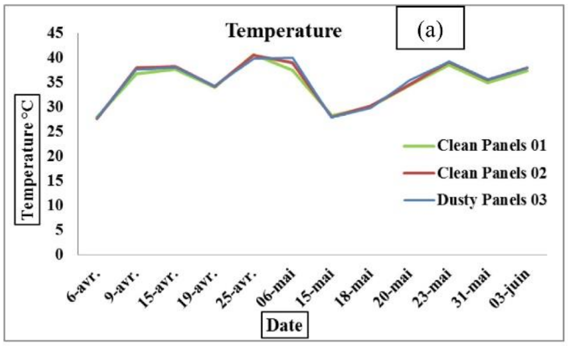
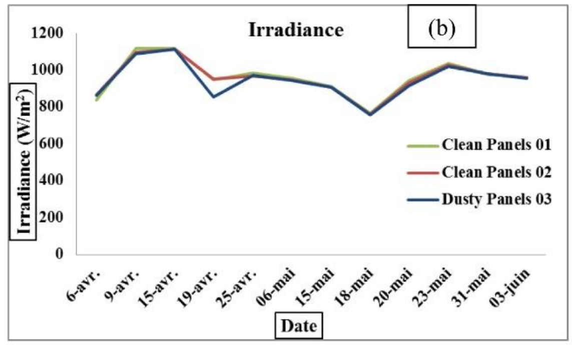


FIGURE 7

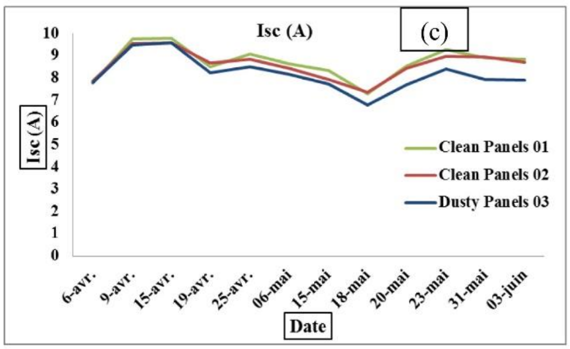
Power variation over time for the three strings of the studied panels. [20]



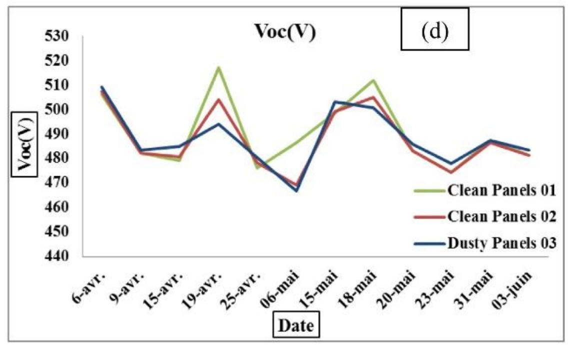
(a): Temperature variation, for strings 1, strings 2 and strings 3



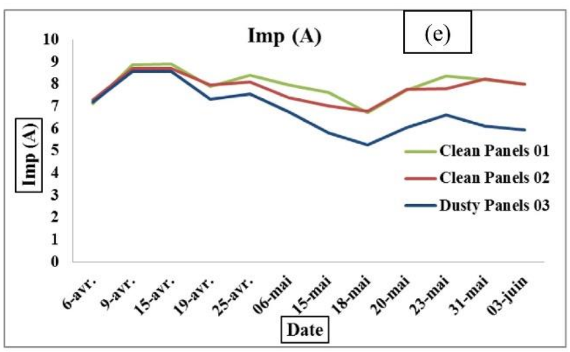
(b): Irradiance variation for strings 1, strings 2 and strings 3



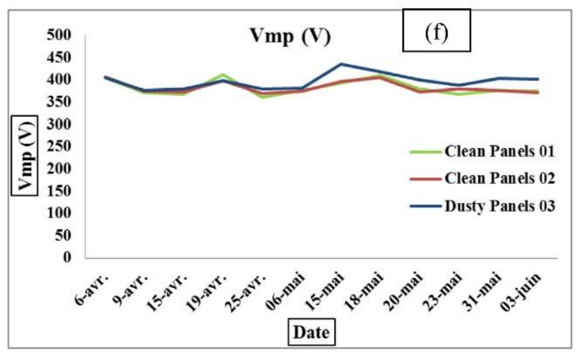
(c): Variation of short-circuit current for strings 1, strings 2 and strings 3



(d): Variation of open circuit voltage (Voc) for strings 1, strings 2 and strings 3



(e): Current at maximum power variation for strings 1, strings 2 and strings 3



(f): Voltage at maximum power variation for strings 1, strings 2 and strings 3

FIGURE 8

(a): Temperature variation, for strings 1, strings 2 and strings 3.
(b): Irradiance variation for strings 1, strings 2 and strings 3.
(c): Short-circuit current for strings 1, strings 2 and strings 3.
(d): Open circuit voltage (Voc) for strings 1, strings 2 and strings 3.
(e): Current at maximum power for strings 1, strings 2 and strings 3.
(f): Voltage at maximum power for strings 1, strings 2 and strings 3.
[21]

1.3. Scope

Project scope is the part of project planning that involves determining and documenting a list of specific project goals, deliverables, tasks, costs and deadlines. The following list is the scope statement of the project:

- The Solar Panel Cleaning Robot (SPCR) will use dry cleaning approach which means it will work without using water.
- SPCR will be autonomous which means it will work without human intervention, it will be moving on axial line forward and backward.
- SPCR will be able to travel along any length of the solar panels assembly
- SPCR will be work once per day.
- SPCR will be suitable for solar farms and customized/prepared solar roofs.
- Costs not to exceed 6000 EGP.
- Project close-out before 28/06/2022.

1.4. Goals and Objectives

- ✓ Improve solar panels power generation.
- ✓ Cleaning solar panels form dust and dirt.
- ✓ Develop appropriate mechanism for robot movement on solar panels.
- ✓ Develop effective spiral brush system to clean solar panels.
- ✓ Design a structure to hold the panels and provide the rail for robot movement.
- ✓ Design electrical circuit capable to control the robot.
- ✓ Develop sensors based system for autonomous working.
- ✓ Develop adequate mechanical design for robot body
- ✓ Develop not environmentally harmful (eco-friendly) robot.
- ✓ Ensure that the robot is working well.

1.5. Basic Economy

Sector	Item/s	Cost
Components	4x Motors & Wheels	740
	Solar Panel	426
	Bluetooth	120
	Arduino Uno	250
	2x Motor Drive	130
	Brush	125
	Tools	175
	Matrials	230

	12v DC Motor	234
	Wires	150
	6x Battery	180
	2x Battery holder	70
	Breadboard	50
Operational	Workspace	450
	CNC Stand	550
	CNC Holder	70
	Smith	350
	Craftsman	400
	Transportation	200
	Project book & doucs	500
Risks		600
Total		6000

TABLE 1

Basic Economy

1.6. Guesstimate

Our guesstimate cases:

Resources of fund:

We need to get fund equal to 6000 EGP by the time shown in **FIGURE 9**.

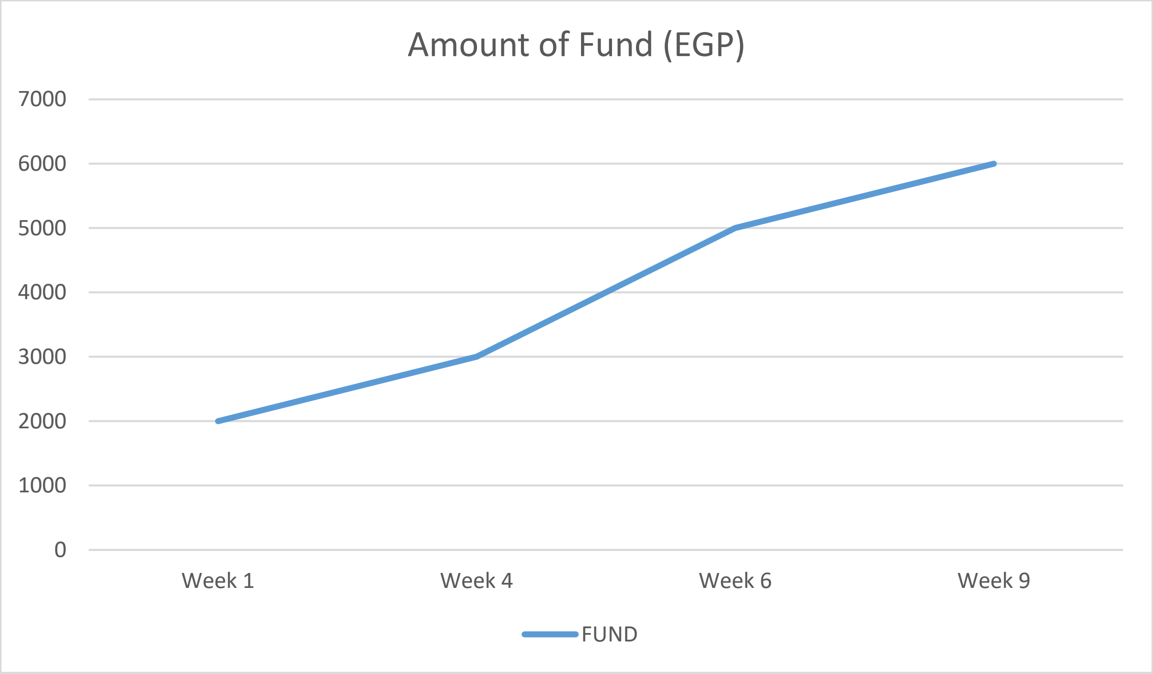


FIGURE 9

Amount of Fund (EGP)

We can get 3 resources of fund equal 6000 EGP as shown blow:

1. Making shares between projects partners.
2. Get fund from collage
3. Get at least one sponsor

Resources of component:
We can get approximately 5 resources as shown blow:

- **A. 3 Local resources:**
    1. Electronic Village
    2. Lampatronics
    3. UGE-one
- **B. 2 international resources:**
    1. Amazon
    2. E-bay

Resources of information and needed knowledge:
We have 3 main resources:

- **A. Online resources:**
    1. Elsevier
    2. ResearchGate
    3. The Egyptian Knowledge Bank

- **B. Companies may be interested at projects:**
    1. Infinity power. 2. KarmSolar

- **C. Our collage PHD and Professors:**
  professors of electrical and mechanical department.

Guestimate of needed time to collect all needed Info for project as shown blow

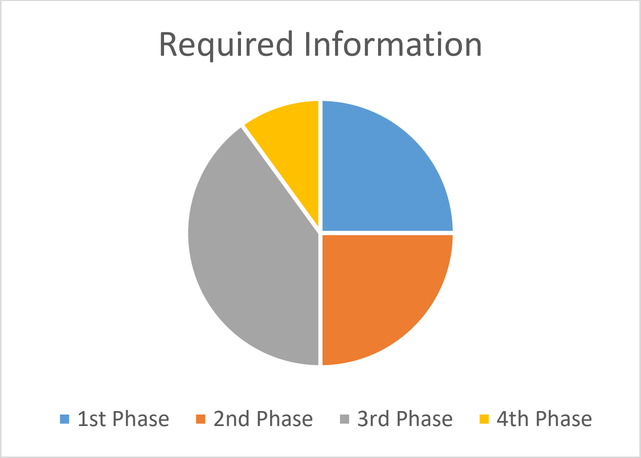


FIGURE 10
Required Information by project phases.

1.7. Stakeholders

"A person or group of people who have a vested interest in the success of an organization and the environment in which the organization operates"

- Team Members
- Supervisor of the project
- Professor and the head of the department of Mechatronics
- Dean of the College of Engineering
- President of Mansoura University
- Government
- Environment and nature
- Organisms and ecosystem
- Solar panels holders
- Solar panels manufacturing companies
- Solar energy operation and maintenance companies
- Energy and fuel company
- Suppliers
- People
- Community and Shareholders
- Industries and companies
- Stock markets

1.6. Identifying Alternatives

1. Waterless vibration systems

Scientists at Heriot-Watt University in Scotland and in a project funded by NASA in the US have developed ways to cause solar panels to vibrate to shake surface dust loose. The Heriot-Watt solution attaches a direct-current (DC) motor to the back of a panel that can be tuned to induce vertical vibrations.

2. Nanoparticle coatings.

Scientists at the International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) unit of India's Department of Science and Technology have developed a solar panel coating to prevent dirt from accumulating in harsh environments. In India, PV panel efficiency is affected by a combination of high temperatures, high humidity, and high pollution.

The nanoparticle-based technology repels dust so that it is easily washed off with water and is highly transparent, so that the coating does not reduce panel efficiency. India’s Marichin Technologies is producing the coating for commercial adoption.

3. Soap-less brushes and sponges

Solar maintenance companies like US-based Bland Company and Premier Solar Cleaning have found that using deionized water with a rolling or vehicle-mounted brush allows them to clean panels without using soap, which leaves a residue that not only shades panels but attracts dirt.

Lubricant manufacturer Polywater produces a Solar Panel Wash to help water lift off grime without leaving a film behind. SunSystem Technology uses a blend of diluted vinegar and hydrogen peroxide to remove dirt.

And, homeowners can wash their solar panels manually using a garden hose and a soft sponge without cleaning agents.

4. Manual cleaning work.

Manually cleaning the PV panels is a good old-fashioned way! Robots, waterless vibration or special coating solutions are innovative and efficient, however, there are many scenarios where these types of solutions can be quite expensive and inefficient. This applies specially for small installations, residential or commercial scale, as well as special structures and installations such as agrivoltaics.

To properly carry out the task, there are some instruments that will help a lot when cleaning solar panels. On the one hand, there are many special brushes that rotate while brushing the soil from the panel. Also, any basic cleaning instrument such as the ones used on car windshields could also help us out.

5. Solar panels cleaning companies.

There are lots of companies provide solar panel cleaning services to help ensure solar system runs at maximum efficiency with regular cleanings. Some solar panels cleaning companies in Egypt are: Benban Solar Power, Gree Solar, BusyBees Egypt, SolarizEgypt, SunBrush, Infinity Power, Golden Sky Solar Systems, Rise-Up-Solar, and Clean Solar.

Phase 2: Project Planning

2.1. Team Members

Project manager (PM) of the team: Mohamed Alaaeldin Mohamed Gaafar. Team members are distributed on the following groups.

2.1.1. Mechanical Group

- Mohamed Alaaeldin Mohamed Gaafar
- Mohamed Hataba
- Kareem Abdelnasser

2.1.2. Technical Group

2.1.2.1. Hardware

- Mohamed Hassan Sherif
- Mohamed Hataba
- Mohamed Alaaeldin Gaafar

2.1.2.2. Software

- Mohamed Hataba
- Mohamed Alaaeldin Mohamed Gaafar
- Mohamed Hassan Sherif
- Ahmed Sherif Salem ElSayed

2.1.3. Operation Group

- Mohamed Alaaeldin Mohamed Gaafar
- Mohamed Hassan Sherif
- Mohamed Hataba
- Mustafa Elsherbiny
- Abdelrahman Ahmed Mostafa
- Abdallah Emad Elhussini
- Hany Samir Abdellatif Atia

2.1.4. Writing Group

- Mohamed Alaaeldin Gaafar
- Mohamed Hassan Sherif
- Ahmed Sherif Salem ElSayed

Thanks to our Dr. Fatma Elerian our team supervisor, and to Eng. Islam Ahmed for their valuable advices and guidance.

2.2. Work Breakdown Structure

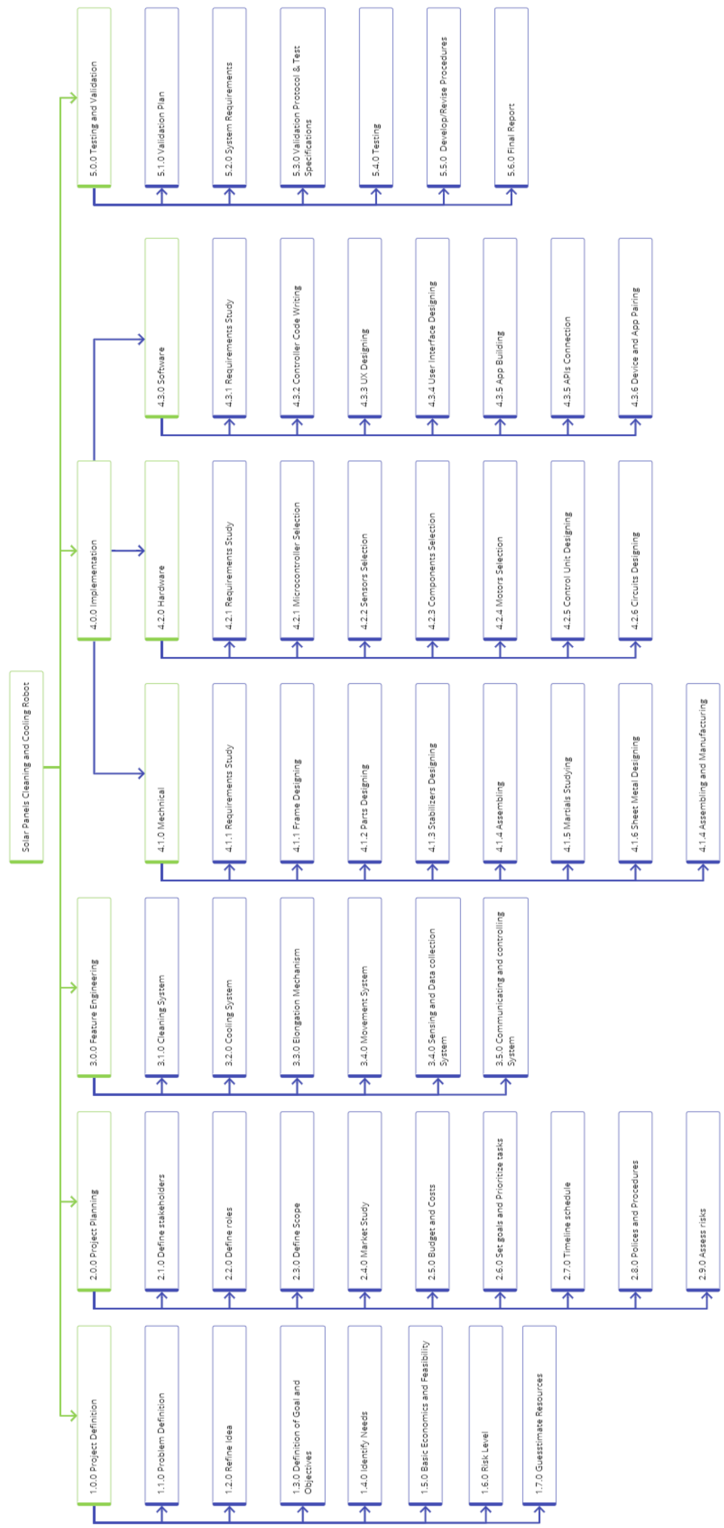


FIGURE 11

Project work breakdown structure

2.3. Risks

Risk Description	Likehood	Management action	Risk owner
Components unavailable in market	High	Prepare/Use local alternative	Market
Components damage	High	Secure spear components/fund	Team
Lack of fund	Low	Spend less	Team
Low quality components	High	Enhance the quality by software correction or relay on other components	Manufacturing companies/ Market
Design failure	Low	Test design before implementation, or change/fix design then and ensure safety	Team
Software Failure	Low	Software testing or fix software	Team
Lack of skilled craftsman	High	Create non-complex design	Market

TABLE 2

Project Risks

2.4. Time Plan

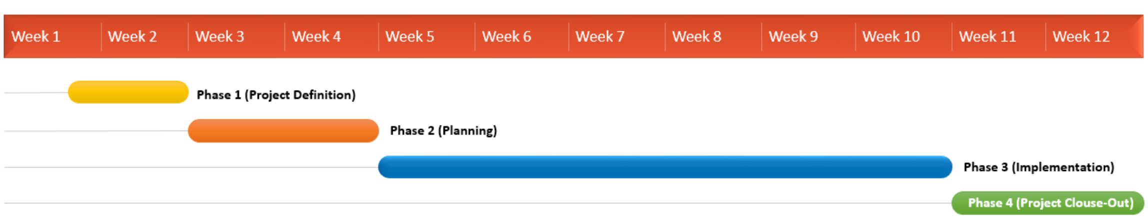


FIGURE 12

Time Plan

Phase 3: Implementation

3.1. Feature Engineering

Product features are a product's discrete areas of new and upgraded functionality that deliver value to customers. Features can refer to capabilities, components, user interface (UI) design, and performance upgrades. [22]

Features may also contain other details, such as timing, status, and assignees, but generally we should have an understanding of each of these elements for any given feature:

- Description: The task or action the user needs to accomplish and how the feature serves them. User challenge: The pain point or challenge experienced by the user that the feature solves for.
- Benefit: The benefit or value provided to the user.
- Goal: The broader product goals or measurable objectives that the feature ties to

The solar panel cleaning robot will have the following features:

- Solar panels dry cleaning.
- Solar panels adequate.
- Autonomous Operating.
- Mobile App User interface.

3.1.1. Solar Panels Dry Cleaning:

Dry cleaning is a way of cleaning solar modules without using water. Solar panel cleaning robots use dry brushes to release dirt from the surface of solar modules. In general, a dry cleaning system has zero waste of water which make it more eco-friendly compared to wet cleaning. Also dry cleaning is suitable for in desert zones, because we cannot make use of water there.

To achieve dry cleaning approach we will use microfiber brush and DC motor.

FIGURE 13

Microfiber brush and DC motor use in the project.

3.1.2. Solar panels adequate:

For the robot to be able to do the work its must be adequate for the solar panels to be used on. For the robot to be adequate for the solar panel we must design the robot on respect of the following parameters:

- Solar panels dimensions.
- Solar panels angle.

3.1.2.1. Solar Panels Dimensions:

Standard residential solar panels, the ones you would have installed onto your homes roof, measure on average 65 inches by 39 inches, or 5.4 feet by 3.25 feet, covering an area of 15 square feet.

There are slight measurement variations depending on the solar panel's manufacturer.

For large scale solar installations like the ones built onto warehouses you could expect solar panels to measure up to 6 feet (these are known as commercial solar panels).

To understand solar panel size, you need to first understand the general makeup of the panel.

Solar panels are made up of smaller individual solar photovoltaic (PV) cells. PV cells always come in the same standard size:156 mm by 156 mm, which is approximately 6 inches long and 6 inches wide.

The majority of small scale solar installations, like the ones you are likely to get on your home, are made up of 60 solar cells.

Commercial solar installations on the other hand, are made up of 72 cells, and can go up to 98 cells or more.

FEATURE	RESIDENTIAL PANELS	COMMERCIAL PANELS
Average Length (inches)	65	78
# of Solar Cells	60	72
Average Width (inches)	39	39
Average Depth (inches)	1.5 - 2	1.5 - 2

Table 2

Solar panel size - residential and commercial panels

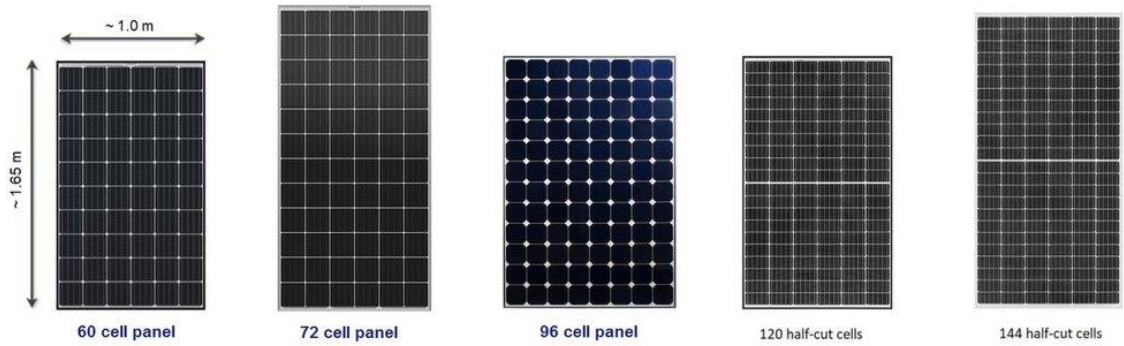


FIGURE 14

Common Solar panel sizes

The concept of the solar panels cleaning robot can work with the different types of panels. For the project characteristics we used a 54x35 cm panel and designed the robot on respect of its dimensions.

FIGURE 15

The panel used on the project

3.1.2.2. Solar Panels Angle:

PV module's performance depends on the azimuth angle and the tilt angle as found in Cairo by [23]. They found that the yearly performance of PV is maximum when incline angles between 20° and 30° and azimuth angle equals.

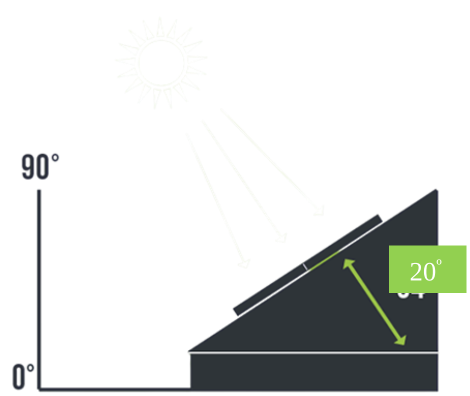


FIGURE 16

Solar panel tilt angel.

3.2. Mechanical Design

3.2.1. *Tools and Requirements*

The requirements of the robot are:

- To be able to move forward and backward on the panels.
- To be anti-slipping.
- Withstand high temperatures
- Light
- Stable and withstand vibrations

In order to design the mechanical system for the robot we used SOLIDWORKS software.

3.2.1.1 SOLIDWORKS

FIGURE 17
Solidworks logo

SolidWorks is a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) application published by Dassault Systèmes.

SolidWorks is a solid modeler, and utilizes a parametric feature-based approach which was initially developed by PTC (Creo/Pro-Engineer) to create models and assemblies. The software is written on Parasolid-kernel.

Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Numeric parameters can be associated with each other through the use of relations, which allows them to capture design intent.

Design intent is how the creator of the part wants it to respond to changes and updates. For example, you would want the hole at the top of a beverage can to stay at the top surface, regardless of the height or size of the can. SolidWorks allows the user to specify that the hole is a feature on the top surface, and will then honor their design intent no matter what height they later assign to the can.

Features refer to the building blocks of the part. They are the shapes and operations that construct the part. Shape-based features typically begin with a 2D or 3D sketch of shapes such as bosses, holes, slots, etc. This shape is then extruded to add or cut to remove material from the part. Operation-based features are not sketch-based, and include features such as fillets, chamfers, shells, applying draft to the faces of a part, etc.

3.2.2. Robot Mechanism

Mechanism is a system of parts working together in a machine; a piece of machinery.

The mechanism of the robot consists of the following parts:

- Robot body
- Actuators and Sensors
- Wheels
- Spiral brush

FIGURE 18

Robot Mechanism.

3.2.3. Robot Dynamics

Robot dynamics is concerned with the relationship between the forces acting on a robot mechanism and the accelerations they produce. Typically, the robot mechanism is modelled as a rigid-body system, in which case robot dynamics is the application of rigid-body dynamics to robots.

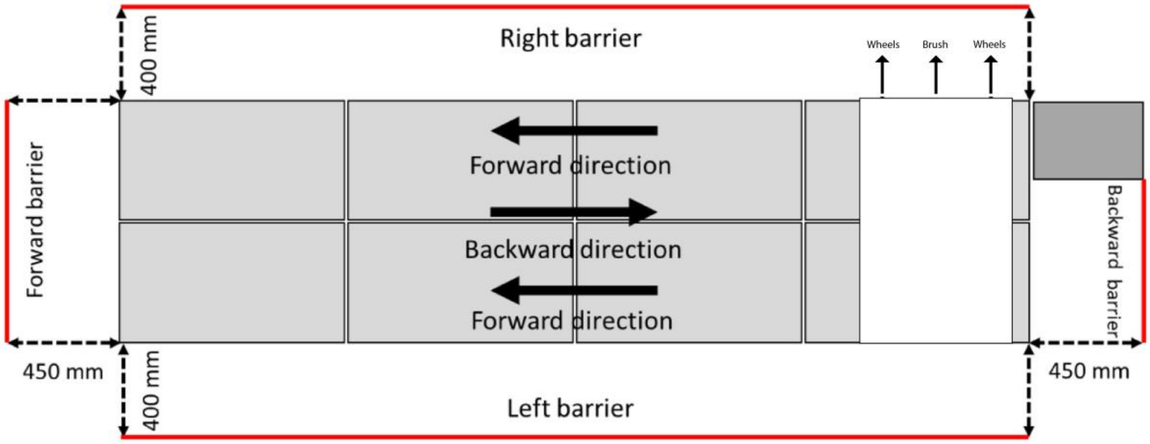


FIGURE 19

Robot Movement.

The robot is moved by four wheels that act like two tracks and anti-slipping pulleys. This solution allows to: (i) better distribute the robot mass on the solar panels; (ii) enhance the traction capability; (iii) minimize the possibility of sliding and slipping; (iv) reduce unwanted motion direction changes that may occur during the PVP array row crossings or when the robot encounters the PVP array fixing clips.

Moments and static loads on the robot caused by the weight of the robot.

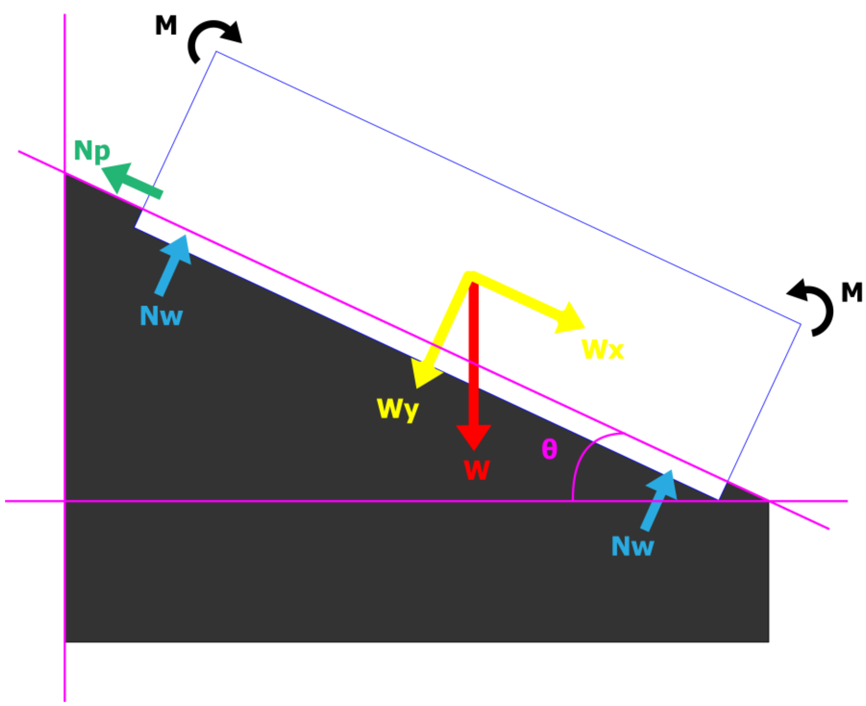


FIGURE 20

Moments and static loads on the robot.

3.2.4. Motors Selection

Direct-current motors transform energy created by electrical current to mechanical energy. It is an important component for industry today. For designers and engineers, it is also important to understand the working principle of DC motors, how to make calculations and how to select a DC motor. We can consider a DC motor in terms of the input-output relationship. The input parameters are the supply voltage (E) and the supply current (I) and the output mechanical parameters are the torque (T) and the rotational speed (ω). A representation of the functional block diagram is shown in Figure 1.

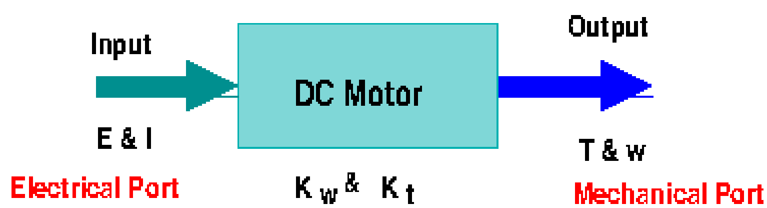


FIGURE 21

DC motor block diagram.

The motor parameters, Kω and Kt, are called motor velocity constant and motor torque constant, respectively. These are specific parameters of a particular motor. Normally these parameters can be found in the motor specification data sheets of DC motors.

The energy conversion is accomplished by the well-known physics principle called motoring action: when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. The direction of the force is determined by the Fleming's left hand rule as illustrated in Figure 2.

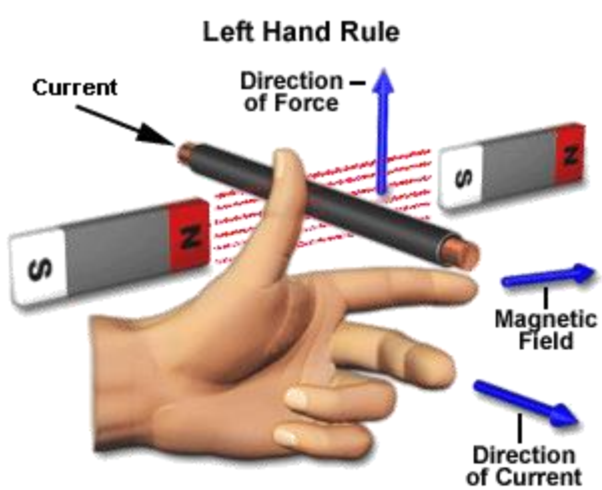


FIGURE 22

Fleming’s left-hand rule.

The direction of the force generated by the magnetic field is perpendicular to both the direction of the current and the field. If we keep the index finger, the thumb and the middle finger perpendicular to each other, and if the middle finger represents the direction of the current and the index finger shows the direction of the magnetic field, then the thumb indicates the direction of the force. This is precisely what happens with the operation of a DC motor.

The main parts of a DC motor consist of a closed-loop conductor carrying the current called the armature, a permanent or an electromagnet (for typical DC motors), a battery or DC voltage source connected to the armature that produces the current through the armature, and brushes and a commutator to ease the rotation of the armature. Because the armature is located inside the magnetic field, once current flows through it, the generated force will actuate to force the armature to rotate. Figure 3 shows the diagram of the main parts of a typical brushed DC motor.

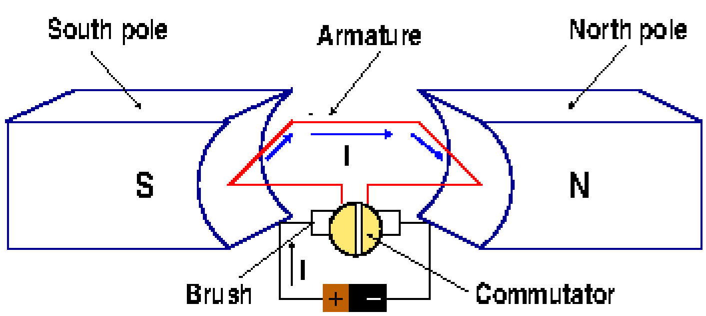


FIGURE 23

Main parts of a DC motor.

Important definitions

Three basic parameters are important to understand motors in general: torque, angular speed and power. A short description of each follows.

Torque

Torque (also known as moment), etymologically derived from the Latin word twist, is defined as a force that produces or tends to produce rotation or torsion. A torque is created when a perpendicular force is applied at the end of a shaft, as is shown in the torque diagram below. The value of the torque is then given by the product of this force times the radius (the distance from the pivot to the location where the force is applied), also called the moment arm.

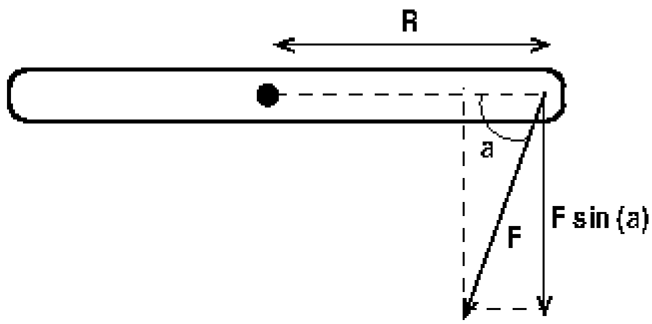


FIGURE 24

The perpendicular component of F produces the torque.

A force F is applied to the shaft at an angle a, as shown. The perpendicular component of this force is Fsin(a) and the moment arm is R. Thus the torque is given by

$$T = FR\sin(a)$$

The SI units of torque are newton-meter (N-m) and the English units are inch-pound (in-lb), feet-pound (ft-lb) or inch-ounce (in-oz).

Rotational speed

Rotational or angular speed is measured in terms of the number of revolutions a shaft makes per unit time. The Greek letter omega, ω, is typically used to represent this quantity, and the units are radian/second (rad/s, SI unit), revolution/second (rps), or, among others, revolution/minutes (rpm). When using this parameter in calculations, we must use rad/s if all the other units are in the SI system, and degrees/sec if we are using the English system. An important conversion to remember is the relationship between rpm and rad/sec, given by

$$\omega_{rad/s} = \omega_{rpm}\left(\frac{2\pi}{60}\right)$$

It is also important to remember the following conversions:

1 revolution = 360°
1 revolution = 2π radians
1 radian = 180/ π degrees
1 degree = π/180 radians

Power

In rotational motion, power is defined in terms of the torque, as follows

$P = T\,\omega$

The standard SI unit of power is watts (W), which is equal to N-m/s, and in the English system we normally use ft-lb/s, or horsepower (hp).

Equivalent circuit of DC motors

A DC motor can be represented by the following circuit (Figure 5):

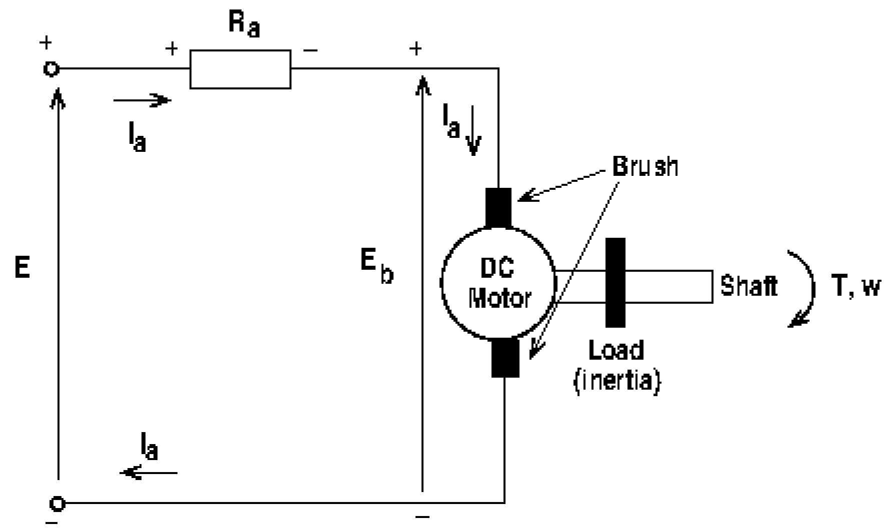


FIGURE 25

DC motor representation.

The motor itself is represented by the circle surrounded by the brushes. The external power or power supply, E, is connected to the brushes through the armature. The armature is represented by its equivalent resistance, Ra. The current through the armature is Ia. The mechanical terminal (output) contains the shaft connected to the motor and the armature. In turns, the combination of armature and shaft is coupled to the mechanical load. When current is flowing through the armature, the magnetic field produces a torque, T, forcing the armature to rotate.

Back e.m.f.

As soon as the armature begins to rotate, a second phenomenon takes place. The armature rotating inside a magnetic field behaves like a generator, inducing an electromotive force (emf) voltage (Eb). This induced voltage, according to Lenz's law, acts in opposite direction to the applied (supply) voltage (E). The induced voltage is known as back or counter emf.

This induced voltage makes the DC motor a self-regulating machine, i.e., it makes the motor to draw as much armature current as is just sufficient to develop the torque required by the load. Back emf in a DC motor regulates the flow of armature current, i.e., it automatically changes the armature current to meet the load requirement.

The back emf value is proportional to the speed of rotation, like in a true generator, and to the flux per pole, and it is given by

$$E_b = \frac{P\phi Z}{60A}$$

Where P is the number of poles, ϕ is the flux per pole, Z is the number of conductor, A is the number of parallel paths, and ω is the motor speed. With the exception of the motor speed, all other parameters in the equation are constants for a particular motor, thus we can write this equation as

$$E_b = K_\omega \omega$$

The constant K ω, as we saw earlier, is called the motor speed constant.

Acceleration of the motor

An equation similar to the last equation can be developed relating the torque and the armature current. It happens that the torque is directly proportional to this current, and given by

T = KtIa

Where Kt is the motor torque constant.

The current flow through the armature is limited only by its resistance, and given by the Kirchhoff current law (KCL):

$$I_a = \frac{E - E_b}{R_a}$$

At the very start of the motor ω = 0, and the induced voltage is Eb = 0. Then the starting current is

$$I_a = \frac{E}{R_a}$$

Starter

The starting current is many times larger than the normal full-load rated current. Because the armature resistance of DC motors is very low, this starting current is dangerously large and can damage the motor windings and other parts of the motor. In order to avoid this, a DC motor must have a starter, which is nothing more than a variable resistance in series with the armature circuit. As the speed of the armature increases, the starter resistance is gradually reduced, so that the motor can attain full speed without the added starter resistance.

Speed regulation

An important feature of DC motors is their ability to maintain the same speed under variable load. To see how this is possible, let's assume that the motor is running at a speed of ω with a back e.m.f. of Eb. If the load is, for instance, increased, the speed will be reduced and Eb will decrease. Therefore the voltage difference E **-** Eb increases, and so does the armature current. With an increase in armature current, the torque will increase forcing an increase of the speed. This is similar to a closed-loop feedback system.

After looking on all parameters we choose the following motors:

- Dc 12V Geared Motor 8.8kg.cm 250 RPM for brush

FIGURE 26

Brush Motor

- DC 6V 30RPM Mini Gear Motor for wheels

FIGURE 27

Wheels Motor

3.2.5. Mobility

Wheeled robots are robots that navigate around the ground using motorized wheels to propel themselves. This design is simpler than using treads or legs and by using wheels they are easier to design, build, and program for movement in flat, not-so-rugged terrain.

The robot use rubber wheels for transitions. Rubber wheels are widely used and provide elasticity and provide good traveling performance on uneven road surface. In addition, rubber wheels are cheaper than urethane wheels.

FIGURE 28

Robot Wheels

3.2.6. Brush Selection

For the robot to be able to do dry cleaning for the panels the use of rotary brush is necessary. Since spiral brush is the best chose to use as rotary brush, but we couldn’t find a spiral brush in the local market, so we developed our rotary brush from combining microfiber brush and steel rod.

The brush we build is capable to assembly with DC motor and operate as rotary brush. The brush embedded in the robot are shown below.

FIGURE 29

The microfiber brush and DC motor use in the project.

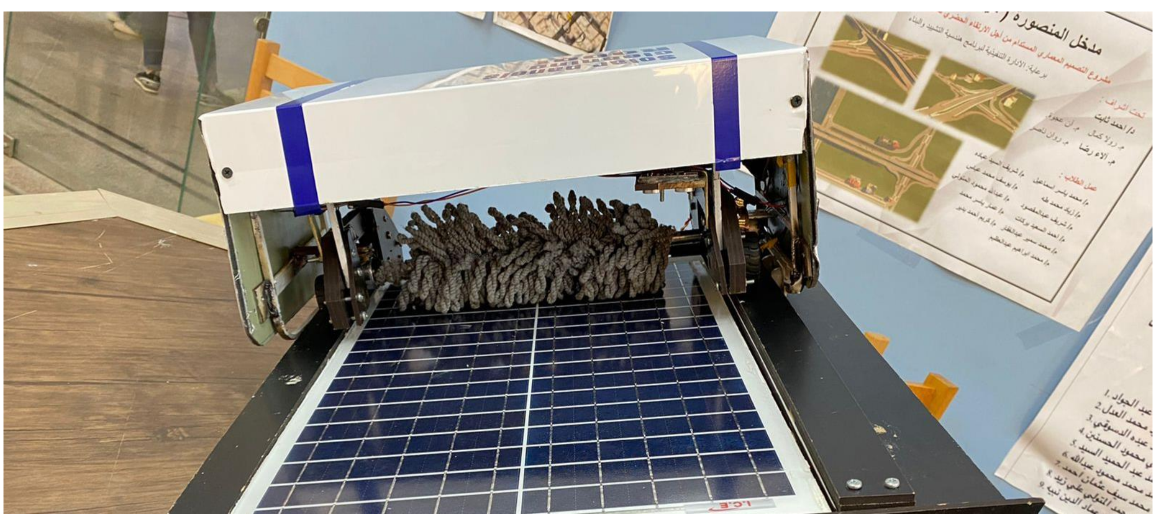


FIGURE 30

Robot brush system

3.2.7. Robot Frame Design

A frame is often a structural system that supports other components of a physical construction. Robot frame is the basic element of the robot, it holds the components together, provide the mechanical stability, and distributes the loads

The computer-aided design (CAD) of the robot frame shown below:

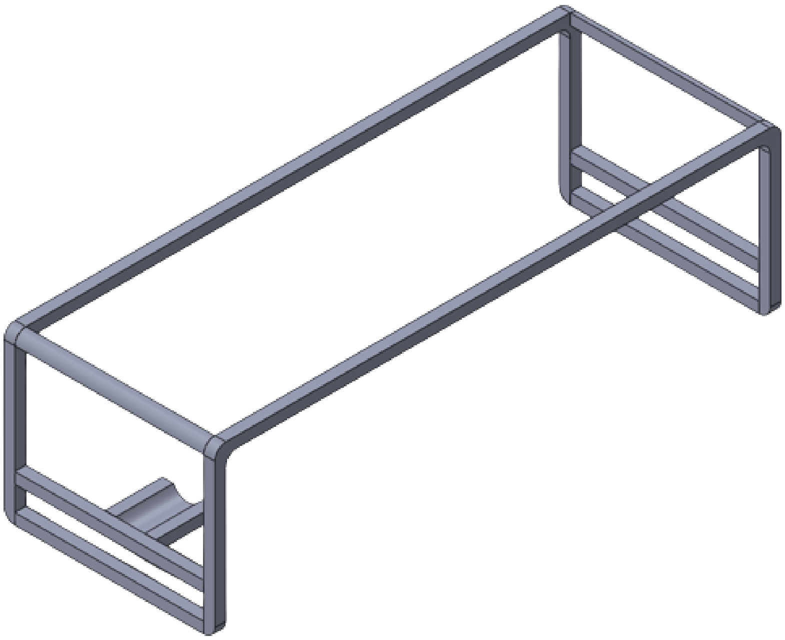


FIGURE 31

Robot frame CAD

The actual design of the robot frame shown below:

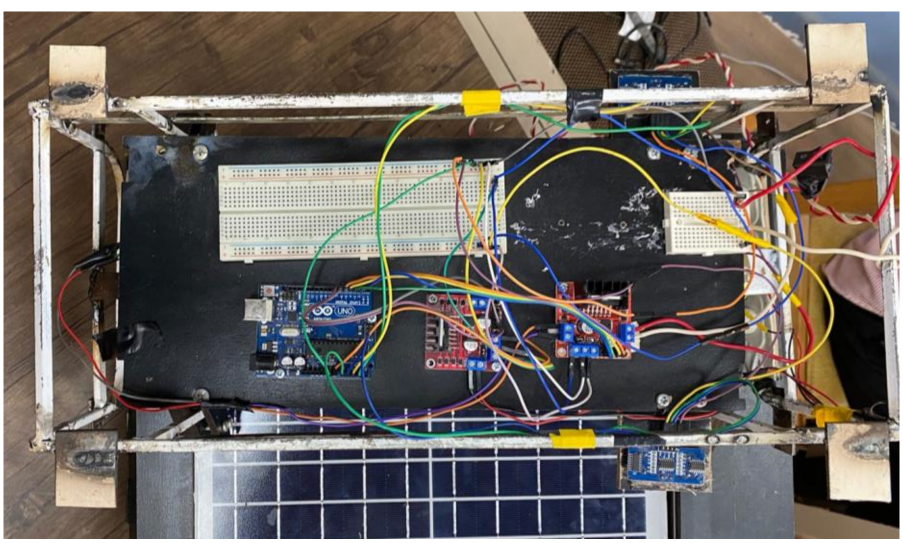


FIGURE 32

The actual design of the robot frame

3.2.8. System Structure Design

Structures are any system that resists vertical or horizontal loads. Structures include large items such as skyscrapers, bridges, and dams, as well as small items such as bookshelves, chairs, and windows.

The Computer-aided design (CAD) of the robot structure shown below:

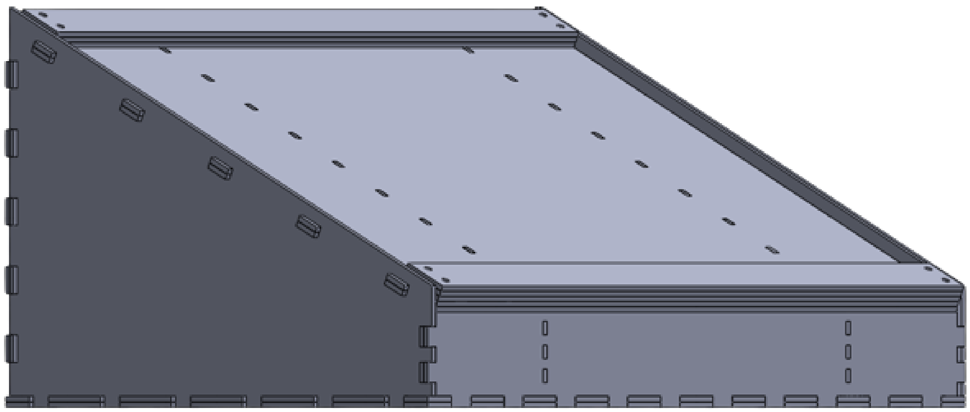


FIGURE 33

Robot structure CAD

The actual design of the robot structure shown below:

FIGURE 34

The actual design of the robot structure

3.2.9. *Materials Selection*

Material selection is a step in the process of designing any physical object. In the context of product design, the main goal of material selection is to minimize cost while meeting product performance goals.

Element	Material	Purpose
Robot Frame	Steel	Strength and bear loads.
Components Connectors	Acrylic wood	Flexibility to work with and easy to customize
Robot Cover	Gladden	Reliability, quality and brightness.
System Structure	Acrylic wood	Light, strength, flexibility to customize.
Brush	Microfiber	Availability in market
Wheels	Rubber	Solid throughout, withstand extreme weather and absorbency

TABLE 4

Material used

3.2.10. *Robot Complete Design*

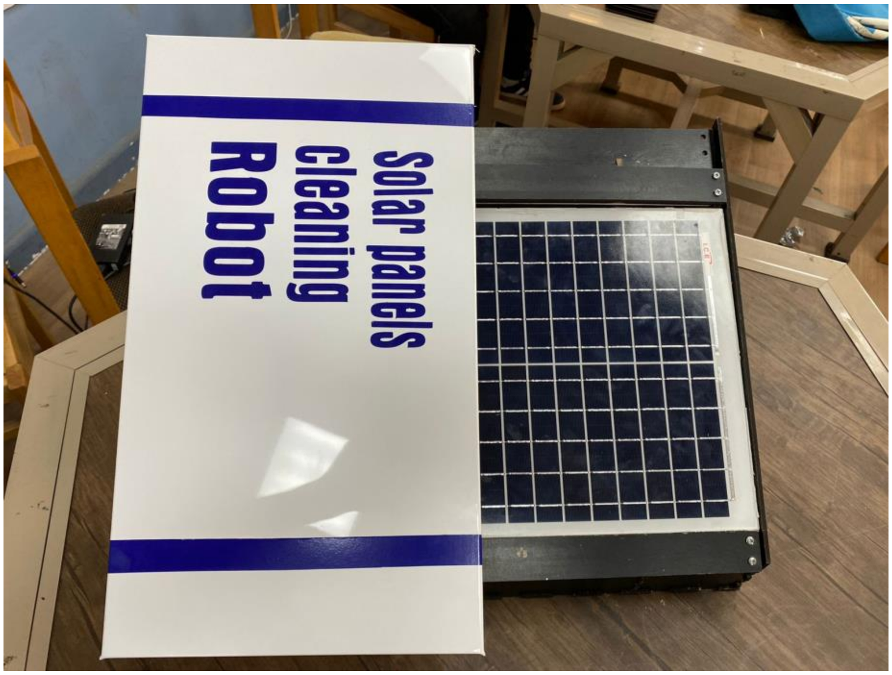


FIGURE 35

Robot complete design

3.3. Electrical Design

3.3.1. Project components:

3.3.1.1. Arduino Uno

One of the most popular Arduino boards out there is the Arduino Uno. While it was not actually the first board to be released, it remains to be the most actively used and most widely documented on the market. Because of its extreme popularity, the Arduino Uno has a ton of project tutorials and forums around the web that can help you get started or out of a jam.

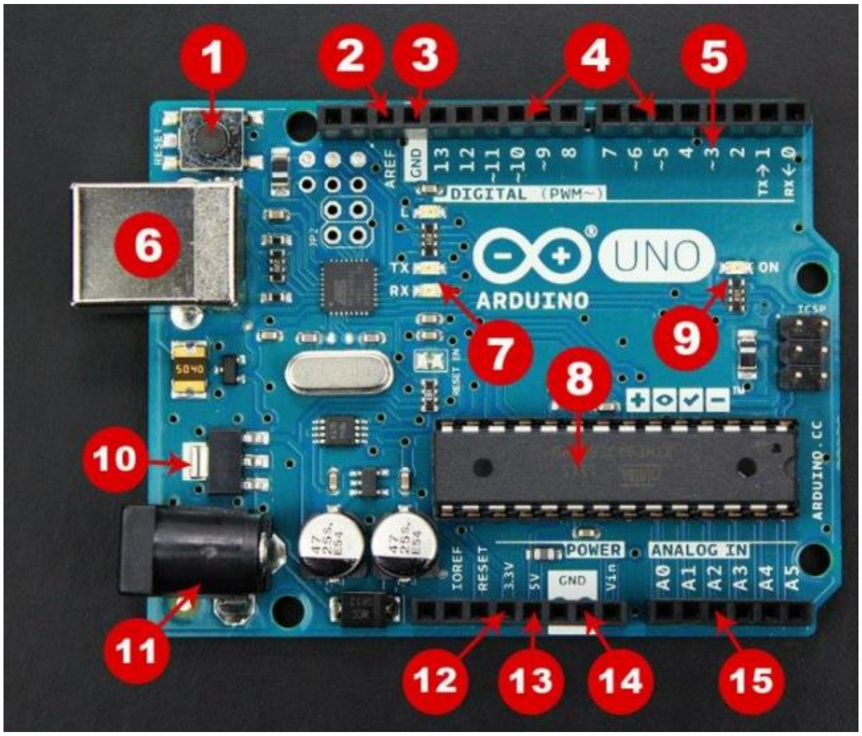


FIGURE 36

Arduino Uno Board Breakdown

Board Breakdown

Here are the components that make up an Arduino board and what each of their functions are.

1. Reset Button – This will restart any code that is loaded to the Arduino board.
2. AREF – Stands for "Analog Reference" and is used to set an external reference voltage
3. Ground Pin – There are a few ground pins on the Arduino and they all work the same
4. Digital Input/Output – Pins 0-13 can be used for digital input or output

5. PWM – The pins marked with the (~) symbol can simulate analog output
6. USB Connection – Used for powering up your Arduino and uploading sketches
7. TX/RX – Transmit and receive data indication LEDs
8. ATmega Microcontroller – This is the brains and is where the programs are stored
9. Power LED Indicator – This LED lights up anytime the board is plugged in a power source
10. Voltage Regulator – This controls the amount of voltage going into the Arduino board
11. DC Power Barrel Jack – This is used for powering your Arduino with a power supply
12. 3.3V Pin – This pin supplies 3.3 volts of power to your projects
13. 5V Pin – This pin supplies 5 volts of power to your projects
14. Ground Pins – There are a few ground pins on the Arduino and they all work the same
15. Analog Pins – These pins can read the signal from an analog sensor and convert it to digital

3.3.1.2. **Arduino Power Supply**

The Arduino Uno needs a power source in order for it to operate and can be powered in a variety of ways. You can do what most people do and connect the board directly to your computer via a USB cable. If you want your project to be mobile, consider using a 9V battery pack to give it juice. The last method would be to use a 9V AC power supply.

FIGURE 37

Arduino Power Supply

3.3.1.3. **Ultrasonic Sensor HC-SR04**

Ultrasonic Sensor HC-SR04 is a sensor that can measure distance. It emits an ultrasound at 40 000 Hz (40kHz) which travels through the air and if there is an object or obstacle on its path It will bounce back to the module. Considering the travel time and the speed of the sound you can calculate the distance.

The configuration pin of HC-SR04 is VCC (1), TRIG (2), ECHO (3), and GND (4). The supply voltage of VCC is +5V and you can attach TRIG and ECHO pin to any Digital I/O in your Arduino Board.

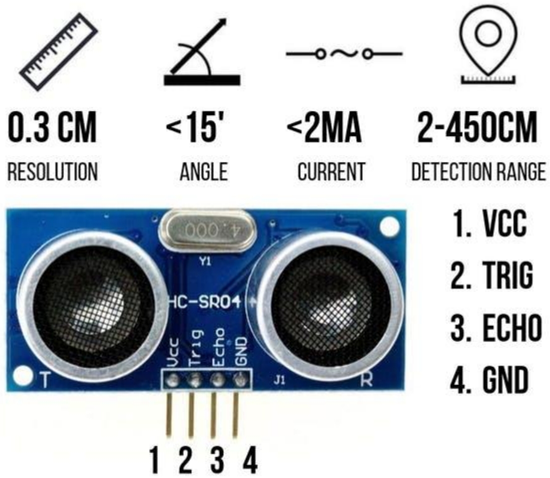


FIGURE 38

Ultrasonic Sensor HC-SR04

The connection of Arduino and Ultrasonic Sensor HC-SR04

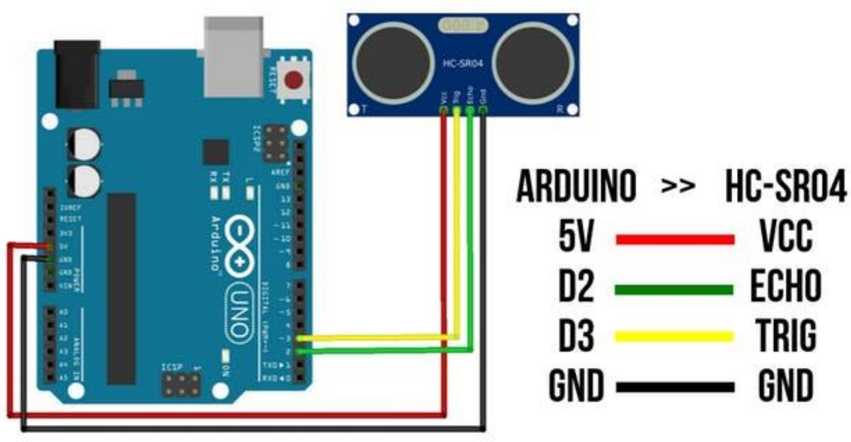


FIGURE 39

The connection of Arduino and Ultrasonic Sensor HC-SR04

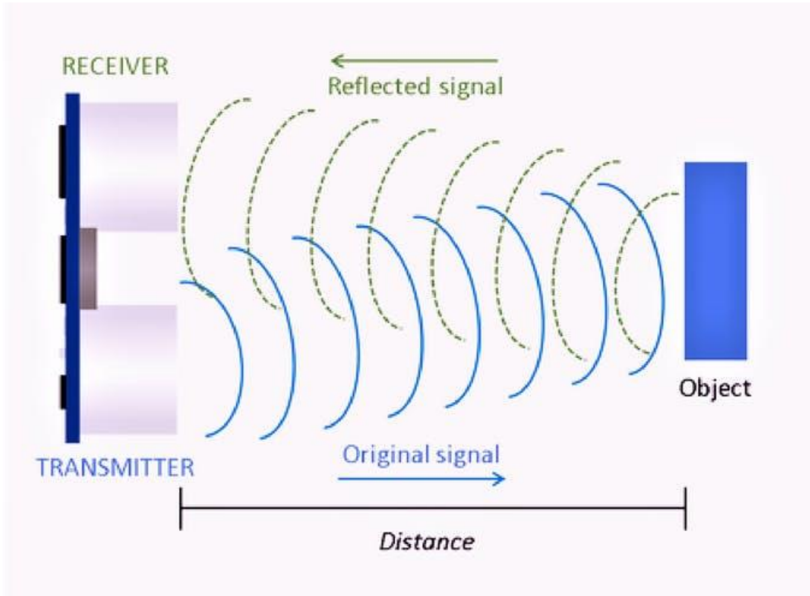


FIGURE 40

Ultrasonic sensor HC-SR04 concept

In order to generate the ultrasound we need to set the Trigger Pin on a High State for 10 µs. That will send out an 8 cycle sonic burst which will travel at the speed sound and it will be received in the Echo Pin. The Echo Pin will output the time in microseconds the sound wave traveled.

Ultrasonic HC-SR04 module Timing Diagram

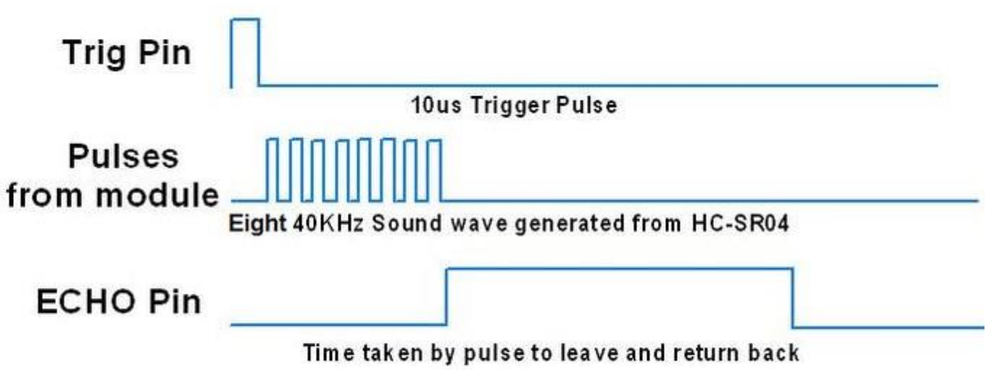


FIGURE 41

Ultrasonic HC-SR04 module Timing Diagram

For example, if the object is 20 cm away from the sensor, and the speed of the sound is 340 m/s or 0.034 cm/µs the sound wave will need to travel about 588 microseconds. But what you will get from the Echo pin will be double that number because the sound wave needs to travel forward and bounce backward. So in order to get the distance in cm we need to multiply the received travel time value from the echo pin by 0.034 and divide it by 2.

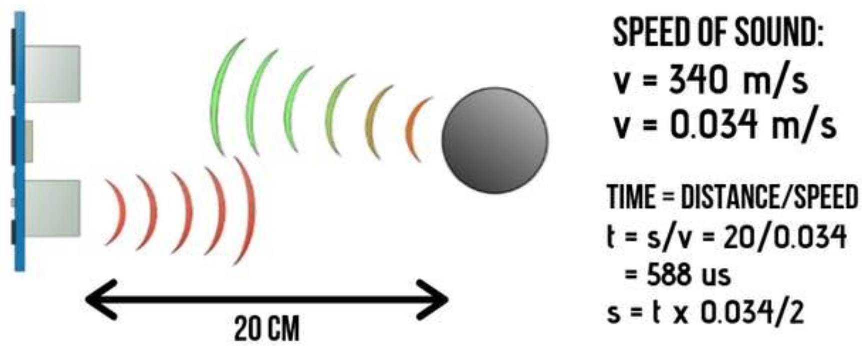


FIGURE 42

Ultrasonic sensor HC-SR04 calculations

For the programming code, first we need to define the Trigger Pin and Echo Pin that connected to Arduino board. In this project EchoPin is attached to D2 and TrigPin to D3. Then define variables for the distance (int) and duration (long).

In the loop first you have to make sure that the trigPin is clear so we have to set that pin on a LOW State for just 2 µs. Now for generating the ultrasound wave we have to set the trigPin on HIGH State for 10 µs. Using the pulseIn()function you have to read the travel time and put that value into the variable “duration”. This function has 2 parameters, the first one is the name of the echo pin and for the second one you can write either HIGH or LOW. In this case, HIGH means that the pulseIn() function will wait for the pin to go HIGH caused by the bounced sound wave and it will start timing, then it will wait for the pin to go LOW when the sound wave will end which will stop the timing. At the end the function will return the length of the pulse in microseconds. For getting the distance we will multiply the duration by 0.034 and divide it by 2 as we explained this equation previously. At the end we will print the value of the distance on the Serial Monitor.

Steps:

1. First do the wiring as shown in the picture
2. Open Arduino IDE Software and write down your code, or download the code below and open it
3. Choose your own Arduino board (in this case Arduino Uno), by selecting Tools > Board > Arduino/Geniuno Uno

4. Choose your COM Port (usually it appears only one existing port), Tools > Port > COM.. (If there are more than one ports, try it one by one)
5. Upload your code by pressing Ctrl + U or Sketch > Upload
6. To display the measurement data you can use Serial Monitor by pressing Ctrl + Shift + M (make sure that the baudrate speed is 9600)

Results:

After uploading the code, display the data with Serial Monitor. Now try to give an object in front of the sensor and see the measurement.

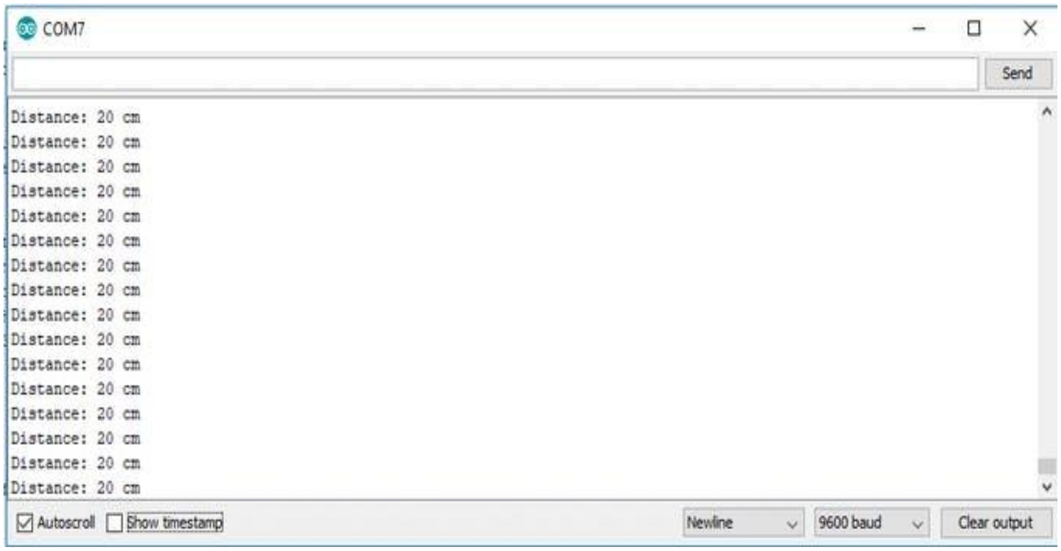


FIGURE 43

Ultrasonic sensor data on Serial Monitor

For the consideration, you can use your manual tape meter to measure the distance and compare it with the distance on Serial Monitor. If you want to display it on LCD, you can follow the second wiring diagram and upload the code below.

Ultrasonic Sensor HC-SR04 with Arduino Code for Ranging TestC/C++

```
// --------------------------------------------------------------
-- //
// Arduino Ultrasoninc Sensor HC-SR04
// Re-writed by Arbi Abdul Jabbaar
// Using Arduino IDE 1.8.7
// Using HC-SR04 Module
// Tested on 17 September 2019
```

```
// ---------------------------------------------------------------
-- //

#define echoPin 2 // attach pin D2 Arduino to pin Echo of HC-SR04
#define trigPin 3 //attach pin D3 Arduino to pin Trig of HC-SR04

// defines variables
long duration; // variable for the duration of sound wave travel
int distance; // variable for the distance measurement

void setup() {
  pinMode(trigPin, OUTPUT); // Sets the trigPin as an OUTPUT
  pinMode(echoPin, INPUT); // Sets the echoPin as an INPUT
  Serial.begin(9600); // // Serial Communication is starting with
9600 of baudrate speed
  Serial.println("Ultrasonic Sensor HC-SR04 Test"); // print some
text in Serial Monitor
  Serial.println("with Arduino UNO R3");
}
void loop() {
  // Clears the trigPin condition
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  // Sets the trigPin HIGH (ACTIVE) for 10 microseconds
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  // Reads the echoPin, returns the sound wave travel time in
microseconds
  duration = pulseIn(echoPin, HIGH);
  // Calculating the distance
  distance = duration * 0.034 / 2; // Speed of sound wave divided
by 2 (go and back)
  // Displays the distance on the Serial Monitor
  Serial.print("Distance: ");
  Serial.print(distance);
  Serial.println(" cm");
}
```

3.3.1.4. The L298N Motor Driver

The L298N Motor Driver is a controller that uses an H-Bridge to easily control the direction and speed of up to 2 DC motors.

Hardware:

1.) The controller can take up to 2 motors. Plug one motor into the terminal labelled OUT1 and OUT2. Plug the second motor into the terminal labelled OUT3 and OUT4:

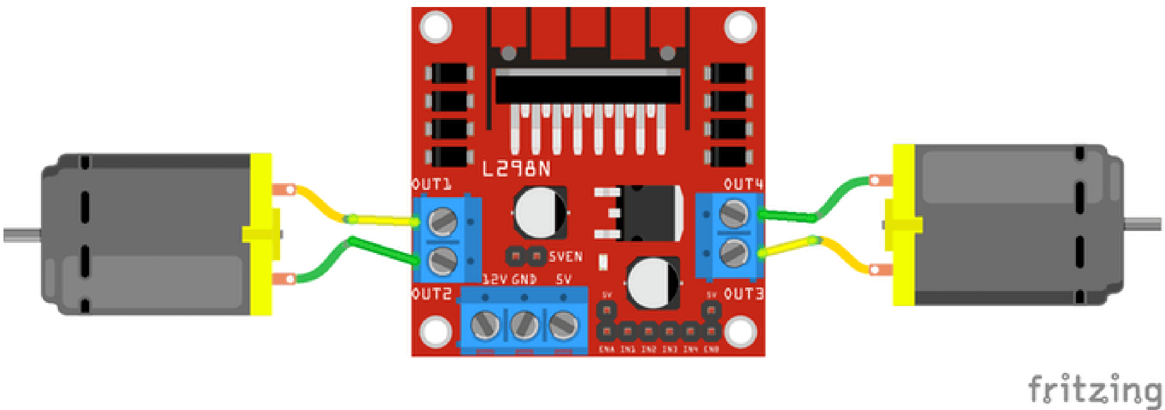


FIGURE 44

L298N Motor to motors

2.) The row of pins on the bottom right of the L298N control the speed and direction of the motors. IN1 and IN2 control the direction of the motor connected to OUT1 and OUT2. IN3 and IN4 control the direction of the motor connected to OUT3 and OUT4. Here I plugged them into pins 2, 3, 4, and 5 on the Arduino.

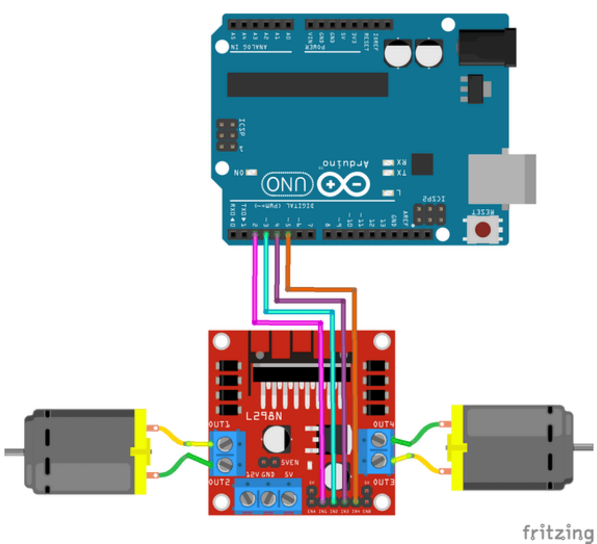


FIGURE 9

L298N Motor with Motors to Arduino

3.) You can power the L298N with up to 12V by plugging your power source into the pin on the L298N labelled "12V". The pin labelled "5V" is a 5V output that you can use to power your Arduino. Here are some ways to wire it depending on your use case:

Powering Arduino with L298N

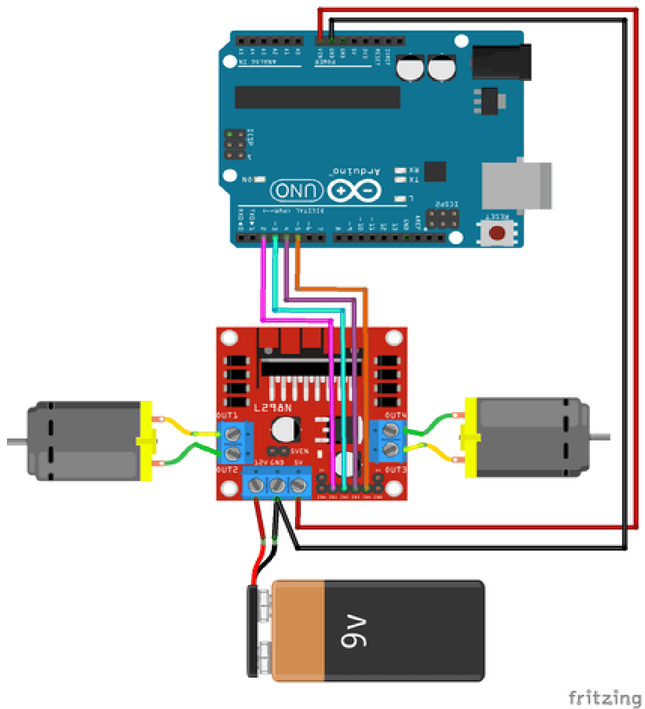


FIGURE 45

Powering Arduino with L298N

Powering L298N and Arduino Separately:

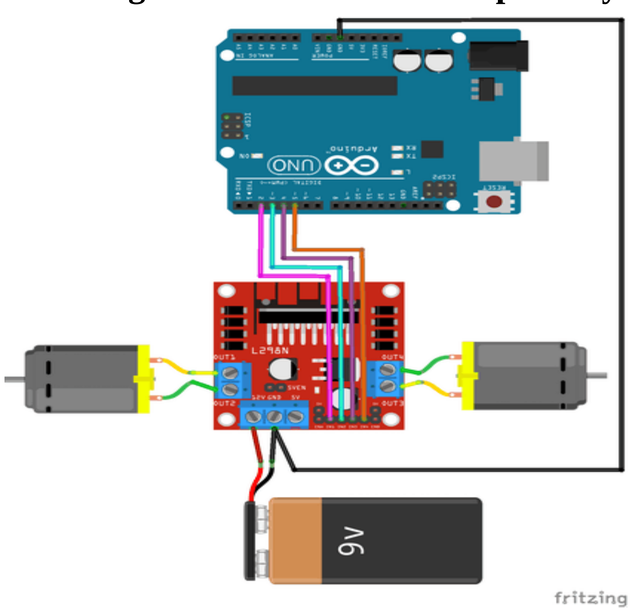


FIGURE 9

Powering Arduino with L298N

Powering L298N with Arduino:

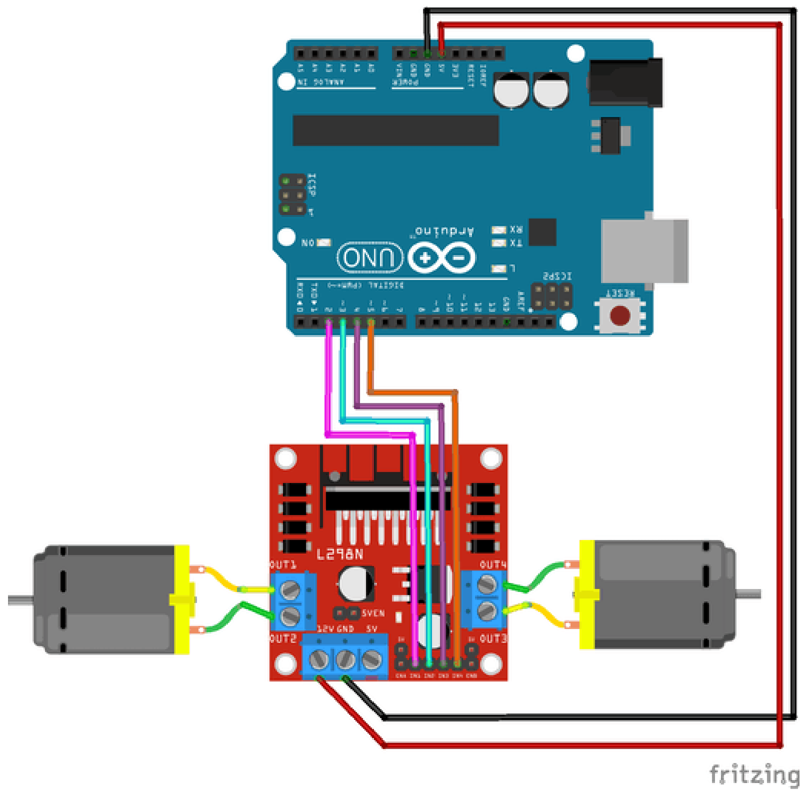


FIGURE 46

Powering L298N with Arduino

Software:

4.) Write the code. Setting IN1 to HIGH and IN2 to LOW will cause the left motor to turn a direction. Setting IN1 to LOW and IN2 to HIGH will cause the left motor to spin the other direction. The same applies to IN3 and IN4. Here is a short example (You can download the full code in the "Code" section at the bottom of the page):

```
digitalWrite(motor1pin1, HIGH);
digitalWrite(motor1pin2, LOW);

digitalWrite(motor2pin1, HIGH);
digitalWrite(motor2pin2, LOW);
```

Speed:

5.) You can change the speed with the EN pins using PWM. ENA controls the speed of the left motor and ENB controls the speed of the right motor. Here I plugged them into pins 9 and 10 on the Arduino. This is optional and the motors will still run if you don't do this.

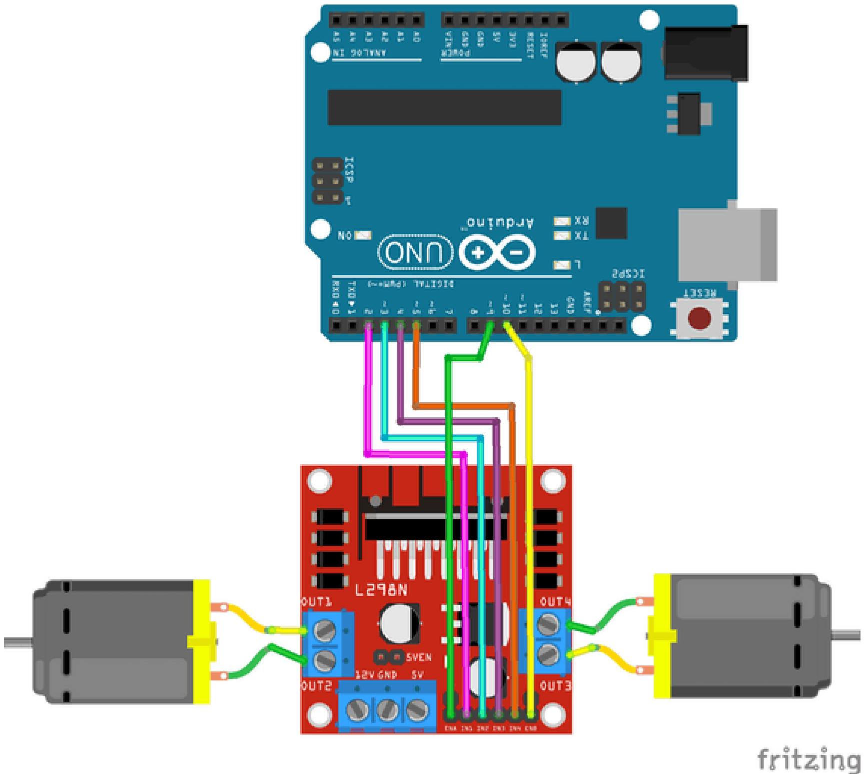


FIGURE 47

Motor speed with Arduino

6.) To change the speed in the code, use the analogWrite() function on the ENA and ENB pins.

analogWrite(ENA_pin, 50);

Code without speed controlC/C++

```
int motor1pin1 = 2;
int motor1pin2 = 3;

int motor2pin1 = 4;
int motor2pin2 = 5;

void setup() {
  // put your setup code here, to run once:
  pinMode(motor1pin1, OUTPUT);
  pinMode(motor1pin2, OUTPUT);
  pinMode(motor2pin1, OUTPUT);
  pinMode(motor2pin2, OUTPUT);
```

```
}

void loop() {
  // put your main code here, to run repeatedly:
  digitalWrite(motor1pin1, HIGH);
  digitalWrite(motor1pin2, LOW);

  digitalWrite(motor2pin1, HIGH);
  digitalWrite(motor2pin2, LOW);
  delay(1000);

  digitalWrite(motor1pin1, LOW);
  digitalWrite(motor1pin2, HIGH);

  digitalWrite(motor2pin1, LOW);
  digitalWrite(motor2pin2, HIGH);
  delay(1000);
}
```

3.3.1.5. Bluetooth HC05 module

A Brief Introduction to Bluetooth Communication and Protocol:

There are several ways for wireless communication such as NRF, ZigBee, Wi-Fi, and Bluetooth.

Bluetooth protocol; an affordable communication method in PAN network, with a maximum data rate of 1Mb/S, working in a nominal range of 100 meters using 2.4 G frequency is a common way of wireless communicating.

HC05 module is a Bluetooth module using serial communication, mostly used in electronics projects.

HC05 Bluetooth module important specifications:

Working voltage: 3.6V – 5V Internal antenna: YesAutomatic connection to the last device: Yes

Sending Data to Arduino via Bluetooth

HC05 module has an internal 3.3v regulator and that is why you can connect it to 5v voltage. But we strongly recommend 3.3V voltage, since the logic of HC05 serial communication pins is 3.3V. Supplying 5V to the module can cause damage to the module.

In order to prevent the module from damages and make it work properly, you should use a resistance division circuit (5v to 3.3v) between arduino TX pin and module RX pin.

When master and slave are connected, blue and red LEDs on the board blink every 2seconds. If they aren't connected, only blue one blinks every 2 seconds.

Circuit

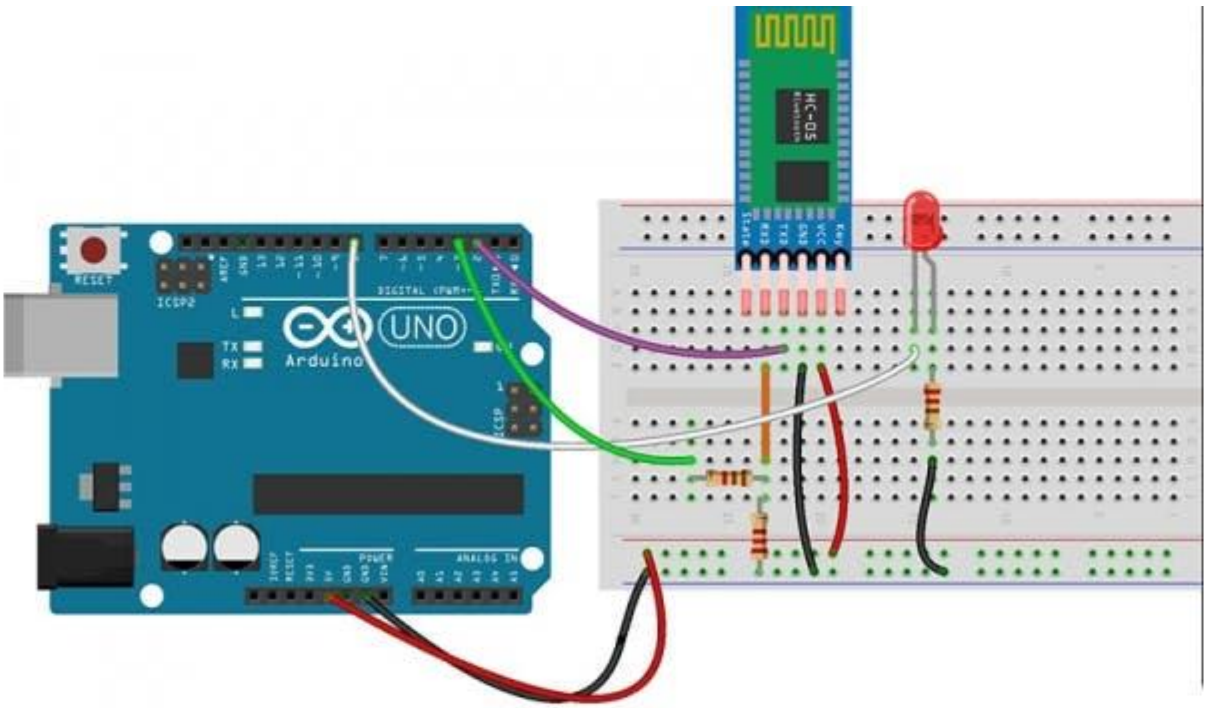


FIGURE 48

HC05 Bluetooth module circuit

Code

In order to communicate with HC05 using Bluetooth, you need a Bluetooth terminal application on your phone. You can use [this one.](#)Now for start transferring data, upload this code on your Arduino and connect HC05 using the app you have just installed. Communication name is HC05, the password is 1234 or 0000 and the transfer baud rate is 9600 by default.

```
/*
HC05 - Bluetooth AT-Command mode
modified on 10 Feb 2019
by Saeed Hosseini
https://electropeak.com/learn/
*/
#include <SoftwareSerial.h>
```

```
SoftwareSerial MyBlue(2, 3); // RX | TX
int flag = 0;
int LED = 8;
void setup()
{
 Serial.begin(9600);
 MyBlue.begin(9600);
 pinMode(LED, OUTPUT);
 Serial.println("Ready to connect\nDefualt password is 1234 or 000");
}
void loop()
{
 if (MyBlue.available())
   flag = MyBlue.read();
 if (flag == 1)
 {
   digitalWrite(LED, HIGH);
   Serial.println("LED On");
 }
 else if (flag == 0)
 {
   digitalWrite(LED, HIGH);
   Serial.println("LED Off");
 }
}
```

Let's take a deeper look at the code and see what each line means:

#include "SoftwareSerial.h"

Library you need for software serial communication. You can download it here.

SoftwareSerial MyBlue(2, 3);

Software definition for serial pins; RX2 & TX3

MyBlue.begin(9600);

Configuring software serial baud rate at 9600

```
void loop()
{
 if (MyBlue.available())
   flag = MyBlue.read();
 if (flag == 1)
 {
   digitalWrite(LED, HIGH);
   Serial.println("LED On");
 }
 else if (flag == 0)
 {
   digitalWrite(LED, HIGH);
   Serial.println("LED Off");
 }
}
```

Reading serial data and Turning LEDs On/Off accordingly.

Sending AT-Commands to HC05 Bluetooth Module and Changing Its Settings

By pressing and holding the button the module switches into AT-command mode. Otherwise, it works in the communication mode.Some modules have a push button in their packages and there is no need to add one anymore.The default baud rate to enter At-command mode is 38400. Now upload this code on your board and set commands using Serial Monitor.

```
/*
HC05 - Bluetooth AT-Command mode
modified on 10 Feb 2019
by Saeed Hosseini
https://electropeak.com/learn/guides
*/
#include "SoftwareSerial.h"
SoftwareSerial MyBlue(2, 3); // RX | TX
void setup()
{
 Serial.begin(9600);
 MyBlue.begin(38400);  //Baud Rate for AT-command Mode.
 Serial.println("***AT commands mode***");
}
void loop()
{
 //from bluetooth to Terminal.
 if (MyBlue.available())
   Serial.write(MyBlue.read());
 //from termial to bluetooth
 if (Serial.available())
   MyBlue.write(Serial.read());
}
```

You will receive the RESPONSE by sending a COMMAND to the module.

3.3.2. Project Circuit

In order to build our robot we use all of these components together as shown in the circuit:

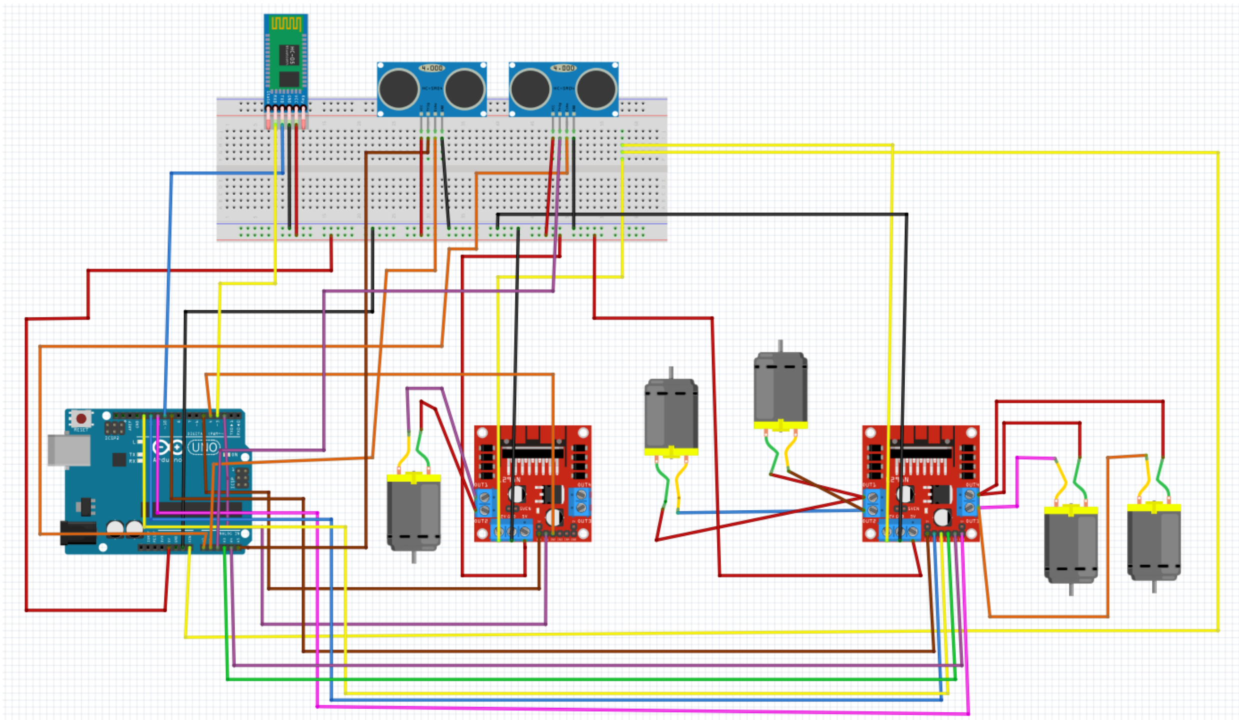


FIGURE 49

Project circuit

The cleaning motor:

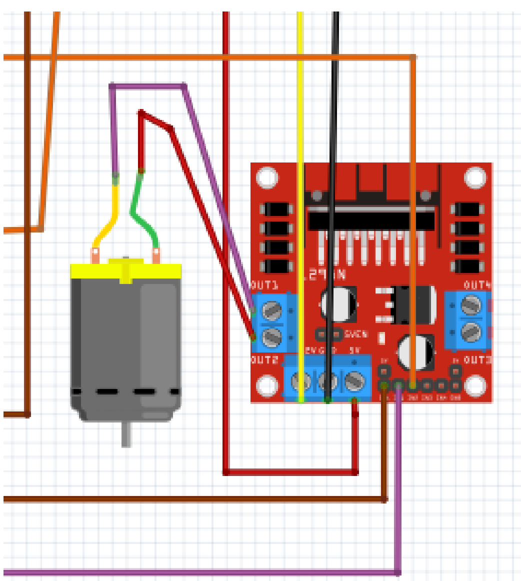


FIGURE 50

The cleaning motor circuit

The motion motors:

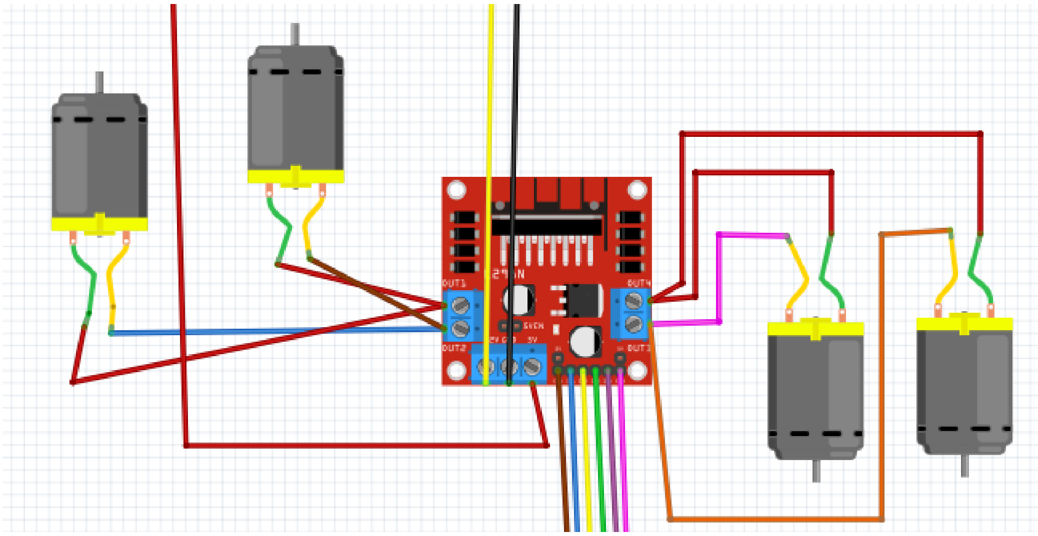


FIGURE 51

The motion motor circuit

3.4. Software Design

Software design is the process of envisioning and defining software solutions to one or more sets of problems. One of the main components of software design is the software requirements analysis (SRA). SRA is a part of the software development process that lists specifications used in software engineering.

3.4.1 *Arduino IDE*

The Arduino Integrated Development Environment - or Arduino Software (IDE) - contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions and a series of menus. It connects to the Arduino hardware to upload programs and communicate with them.

FIGURE 52

Arduino Integrated Development Environment (IDE)

Writing Sketches

Programs written using Arduino Software (IDE) are called sketches. These sketches are written in the text editor and are saved with the file extension .ino. The editor has features for cutting/pasting and for searching/replacing text. The message area gives feedback while saving and exporting and also displays errors. The console displays text output by the Arduino Software (IDE), including complete error messages and other information. The bottom righthand corner of the window displays the configured board and serial port. The toolbar buttons allow you to verify and upload programs, create, open, and save sketches, and open the serial monitor.

3.4.2. Program Code

We wrote the following code lines to develop our robot program:

```
#include <SoftwareSerial.h>
SoftwareSerial Myserial (5,6); // blouthe module tx :5  Rx :6

#define motorRight   2                  // status of motor Right
#define motoorRight  3                 // statue of motor Right
#define motooorspeedRight  9            //control speed of motor
Right

#define motorLeft   7                      //statue of motor Left
#define motoorLeft  8                      //statue of motor Left
#define motooorspeedLeft 10                  //control speed of motor
Left

#define motor3   12                 // status of brush
#define motoor3   13                //status of brush
#define motooorspeed3  11           //control speed of brush

#define trig1     A0
#define echo1     A1

#define trig2     A2
#define echo2     A3

int Bluetooth_Status = 49;
int distance1=0 ;
int ultra1_status = 0;
int t1=0 ;
int distance2=0 ;
int ultra2_status = 0;
int t2=0 ;
void setup()
{
  Myserial.begin(9600);
  Serial.begin(9600);

  pinMode(motorRight , OUTPUT);
  pinMode(motoorRight , OUTPUT);
  pinMode(motooorspeedRight , OUTPUT);

  pinMode(motorLeft , OUTPUT);
  pinMode(motoorLeft , OUTPUT);
  pinMode(motooorspeedLeft , OUTPUT);

  pinMode(motor3 , OUTPUT);
  pinMode(motoor3 , OUTPUT);
  pinMode(motooorspeed3 , OUTPUT);

  pinMode(trig1,OUTPUT);
  pinMode(echo1,INPUT);

  pinMode(trig2,OUTPUT);
  pinMode(echo2,INPUT);
}
```

```
void loop()
{
  if (Serial.available()){
    Bluetooth_Status = Serial.read();
    Serial.println(Bluetooth_Status);
  }
  digitalWrite(trig1,LOW);
  delayMicroseconds(5);
  digitalWrite(trig1,HIGH);
  delayMicroseconds(10);
  digitalWrite(trig1,LOW);
  delayMicroseconds(5);

  t1=pulseIn(echo1,HIGH);
  distance1=t1/57;
  Serial.println(distance1);

  digitalWrite(trig2,LOW);
  delayMicroseconds(5);
  digitalWrite(trig2,HIGH);
  delayMicroseconds(10);
  digitalWrite(trig2,LOW);
  delayMicroseconds(5);

  t2=pulseIn(echo2,HIGH);
  distance2=t2/57;
 Serial.println(distance2);

if(Bluetooth_Status == 49 && distance1 <= 9)
{
     ForwordMotor();
     BrushForword();
     ultra1_status = 1;

}else if(ultra1_status == 1 && distance1 >= 9)
{
     BackwordMotor();
     BrushBackword();
     ultra1_status = 2;

}else if(Bluetooth_Status == 49 && distance2 <= 9)
{
     BackwordMotor();
     BrushBackword();
     ultra2_status = 1;

}else if(ultra2_status == 1 && distance1 >= 9)
{
     ForwordMotor();
     BrushForword();
     ultra2_status = 2;

}else if(distance1 >= 9 && distance1 >= 9)
{
     StopMotor();
     BrushStop();
```

```
}

if( ultra1_status == 2 && distance2 >= 9)
{
      StopMotor();
      BrushStop();
      ultra1_status = 0;
      ultra2_status = 0;
      delay(86500);

}else if( ultra2_status == 2 && distance1 >= 9)
{
      StopMotor();
      BrushStop();
      ultra1_status = 0;
      ultra2_status = 0;
      delay(86500);
}

}
void ForwordMotor (void)
{
  digitalWrite(motooorspeedRight,HIGH);
  digitalWrite(motorRight, HIGH);
  digitalWrite(motoorRight, LOW);

  digitalWrite(motooorspeedLeft,HIGH);
  digitalWrite(motorLeft, HIGH);
  digitalWrite(motoorLeft, LOW);
}
void BackwordMotor(void)
{
  digitalWrite(motooorspeedRight,HIGH);
  digitalWrite(motorRight, LOW);
  digitalWrite(motoorRight, HIGH);

  digitalWrite(motooorspeedLeft,HIGH);
  digitalWrite(motorLeft, LOW);
  digitalWrite(motoorLeft, HIGH);
}
void StopMotor(void)
{
  digitalWrite(motooorspeedRight,HIGH);
  digitalWrite(motorRight, LOW);
  digitalWrite(motoorRight, LOW);

  digitalWrite(motooorspeedLeft,HIGH);
  digitalWrite(motorLeft, LOW);
  digitalWrite(motoorLeft, LOW);
}
void BrushForword(void)
{
  analogWrite(motooorspeed3,255);
  digitalWrite(motor3, HIGH);
  digitalWrite(motoor3, LOW);
}
void BrushBackword(void)
```

```
{
  analogWrite(motooorspeed3,255);
  digitalWrite(motor3, LOW);
  digitalWrite(motoor3, HIGH);
}
void BrushStop(void)
{
  analogWrite(motooorspeed3,0);
  digitalWrite(motor3, LOW);
  digitalWrite(motoor3, LOW);
}
```

3.4.3. App Design

In information technology, an application (app), an application program, or application software is a computer program designed to help people perform an activity. Depending on the activity for which it was designed, an application can manipulate text, numbers, audio, graphics, and a combination of these elements.

3.4.3.1. MIT App Inventor

MIT App Inventor is a web application integrated development environment originally provided by Google, and now maintained by the Massachusetts Institute of Technology (MIT). It allows newcomers to computer programming to create application software (apps) for two operating systems (OS): Android, and iOS, which, as of 8 July 2019, is in final beta testing. It is free and open-source software released under dual licensing: a Creative Commons Attribution ShareAlike 3.0 Unported license, and an Apache License 2.0 for the source code.

FIGURE 53

MIT App Inventor logo

It uses a graphical user interface (GUI) very similar to the programming languages Scratch (programming language) and the StarLogo, which allows users to drag and drop visual objects to create an application that can run on Android devices, while a App-Inventor Companion (the program that allows the app to run and debug on) that works on iOS running devices are still under development. In creating App Inventor, Google drew upon significant prior research in educational computing, and work done within Google on online development environments.

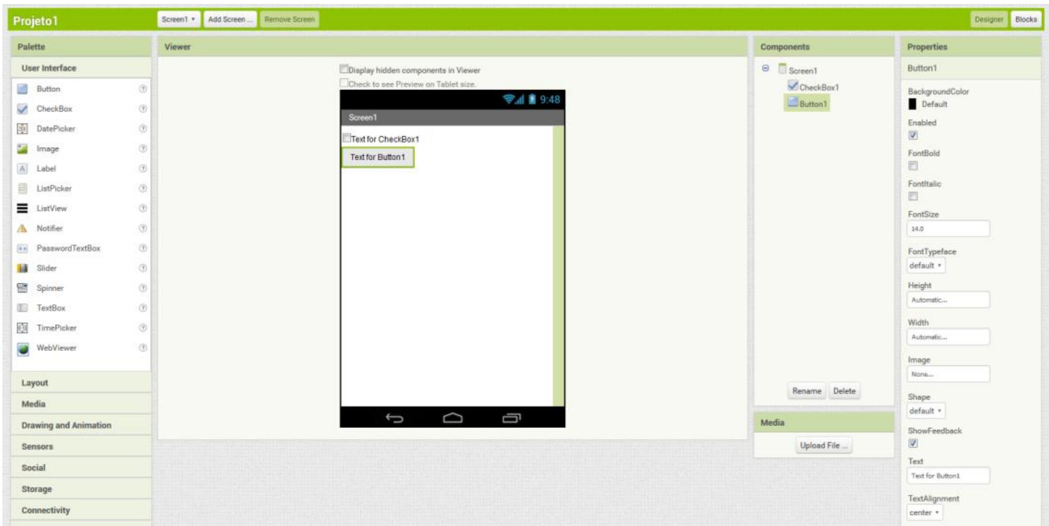


FIGURE 54

MIT App Inventor user interface

App Inventor and the other projects are based on and informed by constructionist learning theories, which emphasize that programming can be a vehicle for engaging powerful ideas through active learning. As such, it is part of an ongoing movement in computers and education that began with the work of Seymour Papert and the MIT Logo Group in the 1960s, and has also manifested itself with Mitchel Resnick's work on Lego Mindstorms and StarLogo.

3.4.3.2. Program Code Blocks

MIT App Inventor uses visual programming.

In computing, a visual programming language is any programming language that lets users create programs by manipulating program elements graphically rather than by specifying them textually.

Here are the code blocks of the app:

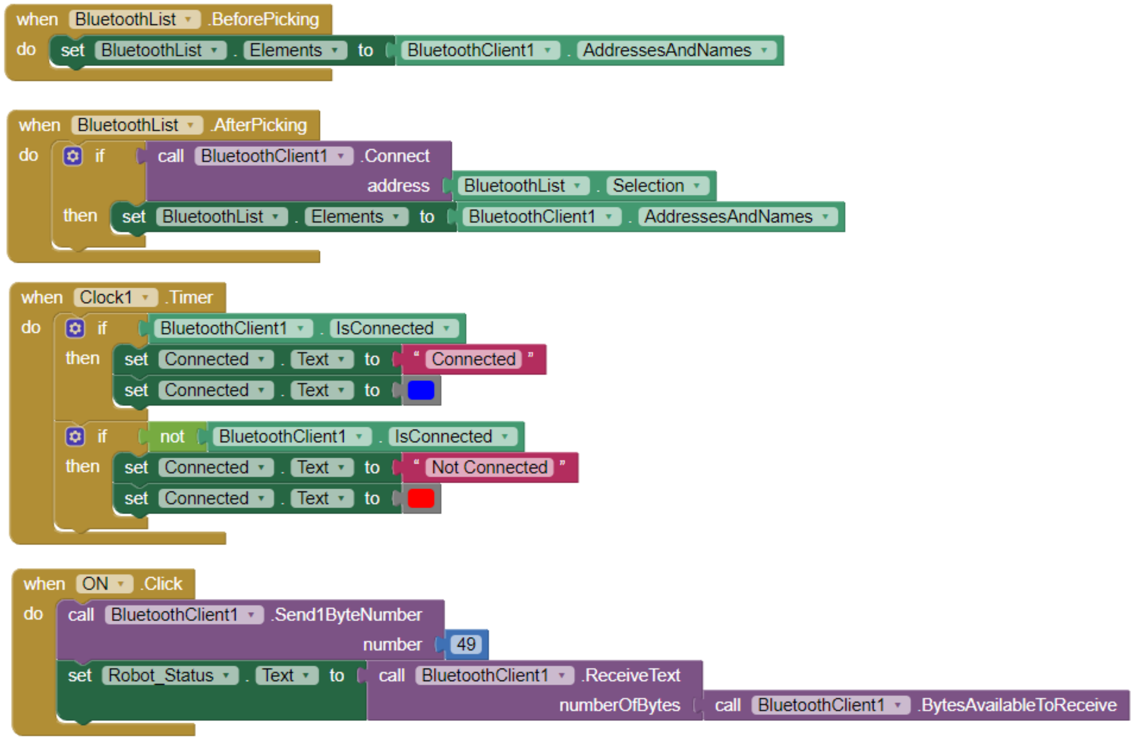


FIGURE 55

Robot app code blocks

3.4.3.3. Android Package Kit (APK)

An APK (Android Package Kit) is the file format for applications used on the Android operating system. APK files are compiled with Android Studio, which is the official integrated development environment (IDE) for building Android software.

FIGURE 56

Android Package Kit (APK)

An APK file includes all of the software program's code and assets. Developers who create applications for use on Android devices must compile their application into the APK format prior to uploading to Google Play, the official marketplace for Android applications. Google Play requires APK files be less than 100 MB in size. To help developers with this limitation, Google Play will host up to two APK expansion files for any additional content required for their application. An APK expansion file is used for storing media files, high-fidelity graphics, or other large assets that would cause an APK to exceed the size limitation.

APK files can also be distributed directly to other Android users for installation on their devices. Android users can grant permission to their device to install unknown apps if they wish to access APK files from another source and install them directly. Android users may wish to install an APK directly if they are beta testing an unreleased version of an application, or due to a device restriction, are unable to download an app from Google Play.

3.4.3.4. Project App

FIGURE 57

Project App.

Phase 4: Project Close-Out

4.1. Results

We want to mention the results of similar study was made by Brian Parrott, Pablo Carrasco Zanini, Ali Shehri, Konstantinos Kotsovos, Issam Gereige on 'robotic dry-cleaning of solar panels using a silicone rubber brush' made in Thuwal, Saudi Arabia at 2017. Which showed the following results. [24]

Primary cleaning results and comparison:

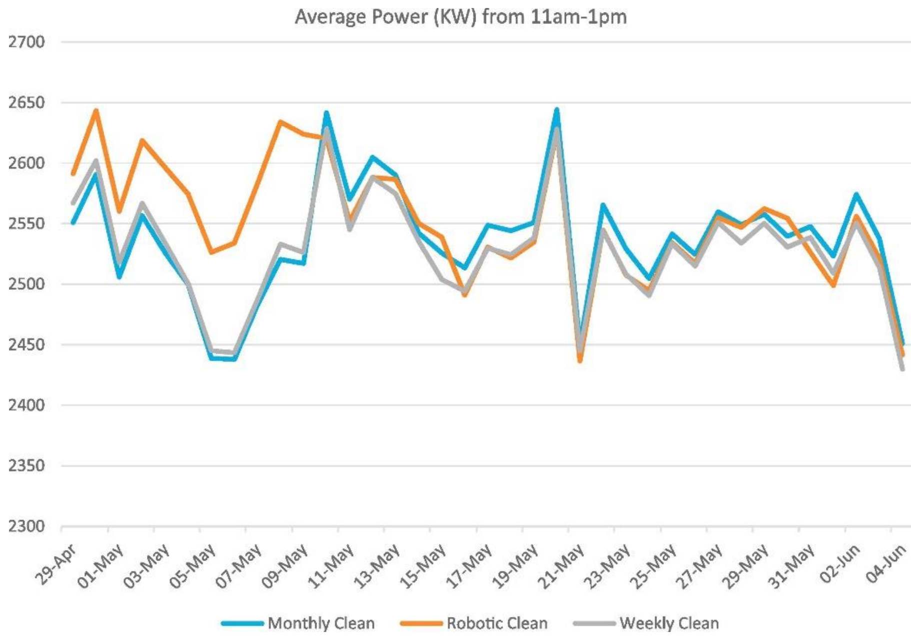


FIGURE 58

Average power generation of solar panels under varying treatment without any normalization.

Cumulative effect of cleaning on power generation:

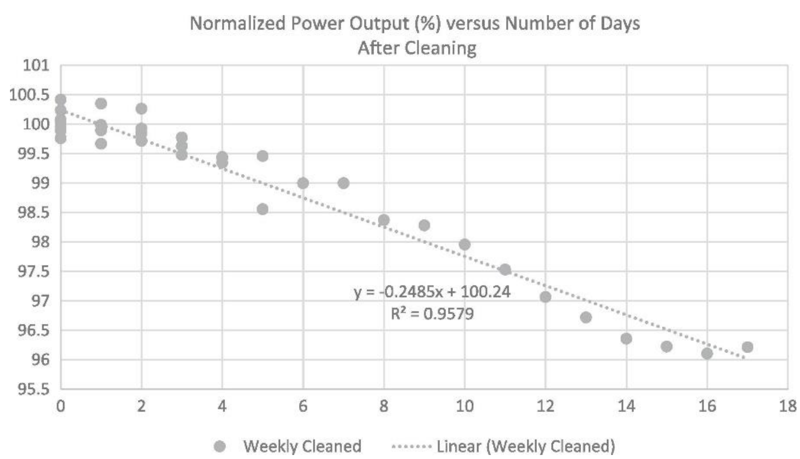


FIGURE 59

Normalized power output of weekly cleaned solar panels versus days since last clean (normalized to robotic cleaning).

4.2. Conclusion

Over time, the surface of PV array in solar power plants becomes dirty due to natural factors such as dust and bird droppings. Therefore, it is necessary to clean the surface of these panels after a while so that the efficiency of solar panels and of course, the efficiency of solar power plants do not decrease significantly. In this project, a robot is designed and built to clean the surface of the PV array, which could move on sloping surfaces and has a high quality in cleaning the surface of solar panels compared. Also, the movement speed, cleaning time, and movement strategy of robot are such that it works better compared to manual cleaning.

Results prove the effectiveness of the proposed robot. Given that the robot's laboratory price is a maximum of 6000 EGP and the efficiency reduction of solar panels without cleaning the panel surface is about 5% in one day, assuming a price of 2 EGP per kW, the maximum cost for the robot will return after one year with the usage of the robot during the night time.

Due to the growing trend of using renewable energy, especially solar energy, high-power solar power plants are being installed and commissioned, and their number will increase in the future. Therefore, cleaning the surface of solar panels to prevent their efficiency loss is essential. Due to a large number of solar panels in power plants, automatic cleaning by robots will be inevitable.

4.3. Feature Work

Some features can be added to the system and the robot, which are:

- Embedded cooling system.
- Embedded wet cleaning system.
- System for cleaning robot brush.
- Data collecting module for solar panel efficiency monitoring.
- Analyzing solar panels performance.
- Data tracking user interface.
- Machine learning model for predicting solar panels performance and recommending best solutions to ensure best performace.

References

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