

FABRICATION OF SOLAR POWERED FLOOR CLEANING ROBOT

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in
Mechatronics

By

AANTO SALOM J (Reg. No. 40090707)

MURALI V (Reg. No. 40090020)



DEPARTMENT OF MECHATRONICS

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade “A++” by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600119

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **AANTO SALOM J (Reg. No. 40090707)** and **MURALI V (Reg. No. 40090020)** who carried out the project entitled "**FABRICATION OF SOLAR POWERED FLOOR CLEANING ROBOT**" under our supervision from December 2023 to April 2024.

Internal Guide

Dr. B. KANIMOZHI, M.E., Ph.D.

Head of the Department

Dr. B. KANIMOZHI, M.E., Ph.D.

Submitted for Viva Voce Examination held on 05/04/2024

Internal Examiner

External Examiner

DECLARATION

We AANTO SALOM J (40090707) and MURALI V (40090020) hereby declare that the Project Report entitled "FABRICATION OF SOLAR POWERED FLOOR CLEANING ROBOT" done by us under the guidance of Dr . B. KANIMOZHI., M.E., Ph.D., is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechatronics.

1. J. Anto salom.

2. Murali V

DATE: 05.04.2024
PLACE: CHENNAI

SIGNATURE OF THE CANDIDATE

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ABSTRACT

This project presents the development of a robotic chase designed to autonomously clean and navigate its environment. The central system interface utilizes an ARDUINO MEGA microcontroller to control the various components. Motor drivers are employed to amplify the microcontroller's signal and power a DC motor responsible for the robot's movement. A second DC motor drives a brush setup for cleaning purposes, automatically rotating during cleaning operations. To navigate the environment, four ultrasonic sensors are used to detect the direction (forward, reverse, left, right) and facilitate obstacle avoidance. The robot also incorporates an RSSI sensor to determine its position. Additionally, a Metal detector sensor is integrated to identify the presence of metal objects. Sensor data and transaction details are conveniently displayed on an LCD screen. A 12V battery serves as the primary power source, supplemented by a solar panel that activates when the battery is low. A charger controller is implemented to monitor solar panel power input. This project amalgamates a range of technologies to create an efficient and self-sustaining robotic chase, capable of intelligently cleaning its surroundings and adapting to different environmental conditions.

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LIST OF ABBREVIATIONS

RSSI	Received Signal Strength Indicator
LCD	Liquid Crystal Display
RPM	Rotation Per Minute
AC	Alternating Current
DC	Direct Current
MM	Millimeter
mA	Mega Ampere

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This article introduces a cutting-edge robotic chase with autonomous cleaning and navigation capabilities, showcasing a sophisticated system powered by an ARDUINO MEGA microcontroller. The heart of this innovation lies in its ability to seamlessly control various components. It utilizes motor drivers to amplify signals and drive a DC motor for the robot's movement, while a second DC motor powers a brush setup for automatic cleaning, rotating during cleaning operations. To navigate its environment effectively, four ultrasonic sensors are strategically placed to detect directions (forward, reverse, left, and right) and facilitate obstacle avoidance, ensuring smooth and safe movement. Adding to its intelligence, the robot incorporates an RSSI sensor for precise position determination and a Metal detector sensor to identify the presence of metal objects in its path. Furthermore, the project includes a user-friendly interface with an LCD screen that conveniently displays sensor data and transaction details, allowing for real-time monitoring and control. The primary power source for this innovative robotic chase is a 12V battery, which is complemented by a solar panel system that activates when the battery level is low. To manage solar panel power input effectively, a charger controller is integrated into the system, ensuring continuous operation in various environmental conditions.

1.2 OBJECTIVE OF SOLAR ROBOT SYSTEM

The scope of this article encompasses the design, development, and implementation of an autonomous robotic chase system with cleaning and navigation capabilities. It includes the integration of advanced sensors, motor control, power management, and an intuitive user interface, creating a self-sustaining solution for efficient cleaning and obstacle avoidance in various environments. In an era where sustainability and efficiency are paramount, these autonomous robots offer a promising solution for maintaining clean floors while harnessing the power of sun. This will

encompass a wide range of topics. We will dissect the intricate designs and architectures of these robots, examining their size, mobility mechanisms and sensor configurations.

1.3 EXISTING SYSTEM

- i. Manual cleaning requires a significant amount of human labor, which can be physically demanding and time-consuming, especially for larger areas or facilities.
- ii. Cleaning processes are inherently slow when performed manually. This leads to longer cleaning durations, potentially disrupting normal operations or activities in the cleaned spaces.
- iii. Human-operated cleaning methods may not be as thorough or consistent as automated solutions, leading to uneven cleaning results and potential oversights.

1.3.1 EXISTING SYSTEM DISADVANTAGES

- i. Limited Working Hours: Human cleaners typically work within specific time frames, such as business hours, leading to limitations in cleaning during off-hours or emergencies.
- ii. Safety Concerns: Manual cleaners may encounter safety risks, especially when cleaning in challenging environments, such as heights or hazardous areas.
- iii. Limited Scalability: Expanding manual cleaning operations to cover larger or additional spaces can be costly and may require hiring more cleaning staff, which is not always feasible.

1.4 PROPOSED SYSTEM

- i. The core function of the system is to autonomously clean its environment. This involves the integration of cleaning mechanisms and the ability to navigate and target areas that require cleaning.
- ii. The system appears to involve trolley navigation, which suggests the robot's ability to move objects or transport items autonomously. This feature can be useful in various industrial and logistical applications.
- iii. This aspect of the system indicates that the robot has the capability to detect and follow trash or objects in its environment. This can be particularly valuable in maintaining cleanliness in public spaces or industrial settings.

1.4.1 PROPOSED SYSTEM ADVANTAGES

- i. **Efficient Resource Utilization:** The system can efficiently process data, optimizing the use of resources such as power and cleaning materials, which can lead to cost savings and reduced environmental impact.
- ii. **Real-time Monitoring:** It offers real-time monitoring of the cleaning and navigation process, allowing for immediate intervention or adjustments when needed, ensuring a high level of control and effectiveness.
- iii. **Enhanced Safety:** In addition to the prevention system, the system can include features like emergency stop buttons and safety protocols that further safeguard both the patient and the equipment in case of unexpected even

CHAPTER 2

LITERATURE SURVEY

Sri Vishva R et.al (2021) develops an autonomous cleaning robot that strikes a balance between achieving high-quality cleanliness and minimizing the time required for cleaning. The challenge is to avoid situations where human intervention becomes necessary, as it can be time-consuming. To address this, we have designed a system that can clean rooms with or without obstacles efficiently. We've simulated the robot's performance in various scenarios. One of the key features of our system is an energy-efficient algorithm for planning the robot's path. This algorithm ensures that the robot takes the shortest possible route to complete its cleaning tasks. By doing so, we optimize the robot's efficiency and reduce the time needed for cleaning

Richard Bormann et.al (2020) discusses the growing significance of visual dirt detection in modern professional cleaning robots. It highlights the importance of this capability in enhancing wet cleaning results and enabling efficient vacuum cleaning tailored to specific needs. The paper introduces a robust, speedy, and dependable system for detecting dirt and office items, which is based on a modified YOLOv3 framework. The system's effectiveness is showcased through various experiments, demonstrating its superiority over existing dirt detection methods. Additionally, the paper presents a dataset generator that allows the creation of numerous realistic training images using a limited set of actual scenes, dirt, and object samples.

Chuong P. Le et.al (2020) explains that a lot of trash gets tossed around throughout production, which is bad for the environment and the health of the people making the goods. Problems with health, such as itchy eyes or chronic obstructive pulmonary disease, and faulty products might result from this waste. The scale of these surroundings makes it difficult for autonomous cleaning robots to cover everything, and they may not have enough dirt storage capacity. Our clever multi-robot dirt cleaning algorithm directs a crew of iRobot-Creates to efficiently clean these expansive areas, providing a sensible solution to the problem. Some places are cleaner than others, and

our algorithm accounts for it. It uses an intelligent path planning algorithm to direct the robotic cleaning crew to maximise suction power in dirtiest locations.

Srikanth Kavirayani et.al (2021) studies and explores the use of robotics and artificial intelligence to enhance the safe and timely delivery of medicines in hospital wards. A specially designed robot is employed to navigate through the wards, delivering medicines efficiently. This is achieved through intelligent algorithms guided by sensors and indicators placed within the wards. The algorithms help the robot find the shortest path to the medicine delivery point and safely exit the ward. Importantly, the system is programmed to prevent collisions with both other robots and humans in its path. Additionally, it ensures that medicines are delivered promptly by searching for the designated indicators. This approach not only ensures the prevention of contagious diseases during medicine delivery but also offers a more efficient alternative to the labor-intensive manual process. The functionality and algorithm of this method have been successfully tested in a prototype arena, using a firebird V robot in a controlled laboratory environment. Overall, this approach saves time, reduces the need for human resources, and can be easily monitored externally from the hospital reception, making it a valuable addition to healthcare delivery.

Bikram Kumar et.al (2020) discusses the automation of logistics for pickups and deliveries within a hospital setting can significantly aid the workforce. This application aims to assign tasks to robots efficiently, with the primary goal of minimizing the total distance travelled by all the robots. In this paper, we introduce two scheduling schemes: the "deep Hungarian" (Hungarian) scheme and the "deep Voronoi" (d-Voronoi) scheme. The d-Hungarian scheme is tailored for environments where job locations are known in advance, while the d-Voronoi scheme does not require prior knowledge of job locations. Through simulation results, our schemes demonstrate their effectiveness in reducing the distance travelled by robots, ultimately optimizing the logistics process within the hospital.

Mrs. Rajeshwari et.al (2023) addresses the topic of graphene Hoover cleaners and how they will meet the high demand in the global industry. A significant role in

residential industries should be reserved for multi-functioning systems that can absorb, desalinate, collect solar energy, and purify water. Graphene may be the material of choice for future innovations that aim to make these electrical gadgets more bendable, small, foldable, and portable. Consequently, Hoover cleaners made of graphene and powered by graphene batteries can have better performance.

Prof. V. M. Dhumal et al. (2022) explains that the purpose of creating the floor cleaning robot was to simplify the process of cleaning floors. This has potential use in power facilities, such as nuclear power plants, where the dangerous radiations are stored and where they might create significant health concerns. We can avoid this by having a robot carry out the entire procedure. A floor cleaning robot would be ideal for universities and other big public spaces with plenty of carpeting and hard floors. We need to clean both big and little places in our industries, and we can do it without hiring cleaners. This will help us save both time and money.

Omur Akyyazi et al. (2019) talks about how they've developed a lightweight and inexpensive SPCR system that uses microcontrollers. Dusting can have a negative impact on PV panel output power, however the suggested solution mitigates this. The system is developed and tested in a very little amount of time. Nevertheless, more testing will be conducted on the gadget to guarantee its dependability. They intend to enhance their project in the future. The reduction of cleaning time and the need for water and electricity storage are two goals of the innovations. Altering the type of brush used might shorten the time it takes to clean. A light deduction circuit will also be incorporated into the system for day and night deduction in the upcoming gadget version.

Ms. G. V. Swathi et al. (2023) explains that the primary goal of the project was to create a robot with the ability to dispense water, sweep the floor, and collect dust. Without human intervention, the robot moves autonomously, and its job is to identify and avoid impediments. The robot can alter its trajectory to avoid obstacles.

Sabiya Kirangi et al. (2023) discusses that the solar-based floor cleaner robot is an innovative solution for daily cleaning tasks in large outdoor spaces. It is easy to

operate, energy-efficient, and environmentally friendly. The ultrasonic sensor and obstacle detection system ensure the safety of the robot and the cleaning area. The use of solar power makes the robot self-sufficient and eliminates the need for constant charging. The solar-based floor cleaner robot can be further developed to include more advanced features such as GPS tracking, Wi-Fi connectivity for remote control, and AI-based obstacle avoidance. The robot can also be designed to work in different terrains and environments, such as grass and sand. With further research and development, the solar-based floor cleaner robot has the potential to become a widely used cleaning solution for large outdoor spaces

CHAPTER: 3

AIM AND SCOPE

3.1 AIM OF THE PROJECT

The aim of a solar power floor cleaning robot is to provide a convenient, efficient, and environmentally friendly way to clean floors. These robots are powered by solar energy, which makes them self-sufficient and reduces the need for fossil fuels. They are also equipped with sensors and navigation systems that allow them to move around independently and clean floors without human intervention.

3.2 SCOPE OF THE PROJECT

The scope of solar power floor cleaning robots is broad and includes a wide range of applications, such as:

- i. Commercial: Solar power floor cleaning robots can be used to clean floors in a variety of commercial settings, such as offices, schools, hospitals, and retail stores. They can also be used to clean outdoor areas, such as sidewalks and patios.
- ii. Industrial: Solar power floor cleaning robots can be used to clean floors in industrial facilities, such as factories and warehouses.
- iii. Residential: Solar power floor cleaning robots can be used to clean floors in homes. They are particularly useful for people who have mobility issues or who simply do not have the time or energy to clean their floors themselves.

In addition to their practical applications, solar power floor cleaning robots can also play a role in reducing our environmental impact. By using solar energy

to power these robots, we can reduce our reliance on fossil fuels and greenhouse gas emissions.

The future scope of solar power floor cleaning robots is promising. As technology continues to advance, we can expect to see robots that are more intelligent, efficient, and affordable. We may also see robots that are capable of performing other tasks, such as vacuuming and dusting.

Here are some specific examples of how solar power floor cleaning robots can be used to improve our lives:

- i. Reduce the burden on healthcare workers: Solar power floor cleaning robots can be used to clean hospitals and other healthcare facilities, freeing up nurses and other staff to focus on patient care.
- ii. Improve indoor air quality: Solar power floor cleaning robots can be used to remove dust, allergens, and other pollutants from the air, making it easier for people with respiratory problems to breathe.
- iii. Make cleaning more accessible: Solar power floor cleaning robots can be used by people with mobility issues or disabilities, making it easier for them to keep their homes clean and tidy.
- iv. Reduce our environmental impact: Solar power floor cleaning robots use renewable energy, which helps to reduce our reliance on fossil fuels and greenhouse gas emissions.

Overall, solar power floor cleaning robots have the potential to make our lives easier and more sustainable.

CHAPTER: 4

MATERIAL AND METHODOLOGY

4.1 INTRODUCTION

The article entails the creation of an advanced robotic cleaning and navigation system designed to autonomously manage and maintain cleanliness in various environments. At its core, the system utilizes an ARDUINO MEGA microcontroller, a powerful and versatile control unit, to orchestrate its intricate operations. One of its primary functions involves the precise control of two DC motors; one propels the robot's movement, while the other drives a specialized brush setup for thorough cleaning. To navigate and interact with its surroundings intelligently, the system employs four ultrasonic sensors that detect obstacles and guide the robot's path in four directions (forward, reverse, left, and right). Additionally, an RSSI sensor is integrated to accurately determine the robot's position, ensuring precise navigation. The system goes beyond mere cleaning; it incorporates a Metal detector sensor to identify the presence of metallic objects in its vicinity, enhancing safety and functionality. User interaction is facilitated through an LCD screen that provides real-time data and transaction details, enabling efficient monitoring and control. Powered primarily by a 12V battery, the system's sustainability is further bolstered by a solar panel, which activates when the battery level is low, ensuring uninterrupted operation. This project represents an amalgamation of cutting-edge technologies, promising an adaptable and self-sustaining robotic solution capable of maintaining cleanliness and safety in diverse environments.

4.2 BLOCK DIAGRAM OF ROBOT CLEANER

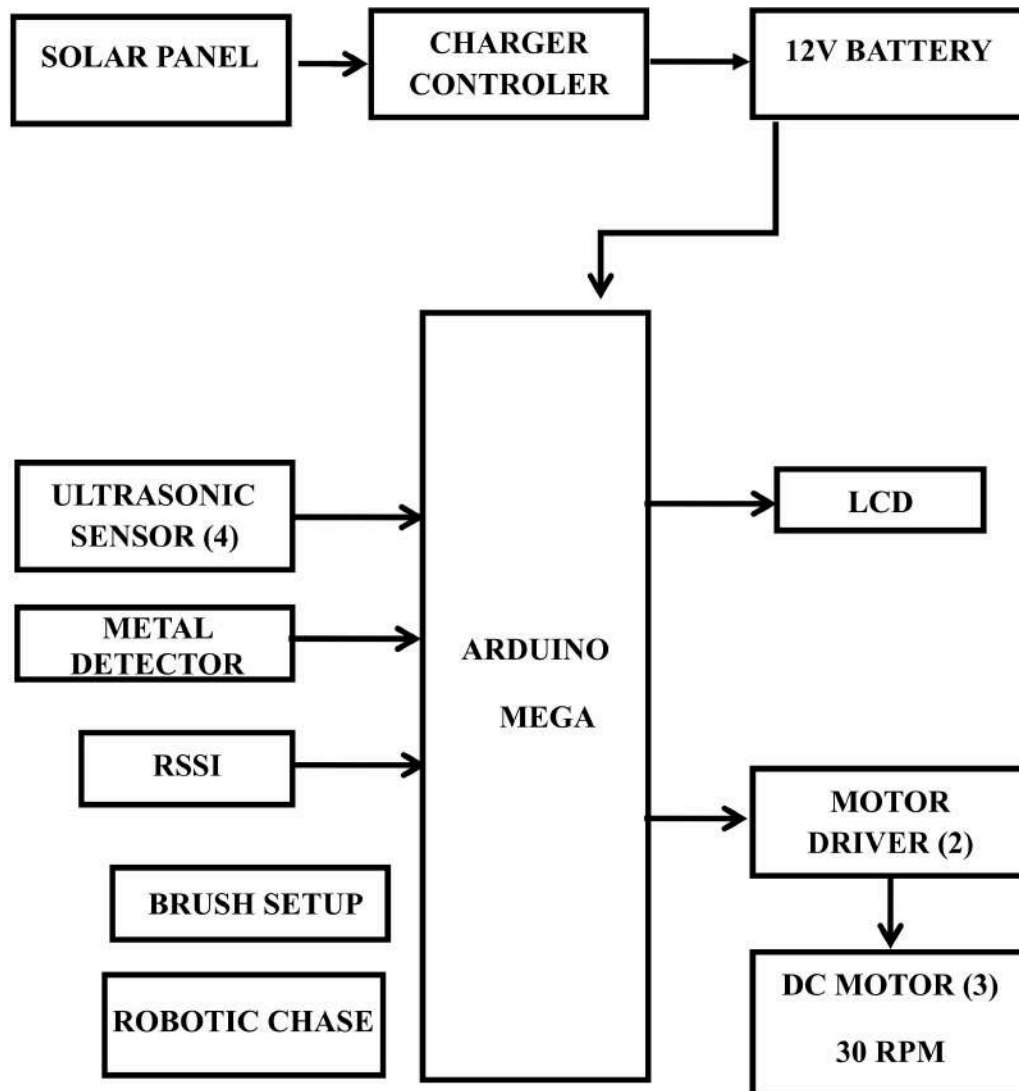


Fig 4.1 Block Diagram Of Robot Cleaner

4.3 MODULES NAME

- i. RENEWABLE ENERGY
- ii. OBSTACLE & METAL DETECTION
- iii. RSSI

4.4 MODULE DESCRIPTION

4.4.1 RENEWABLE ENERGY

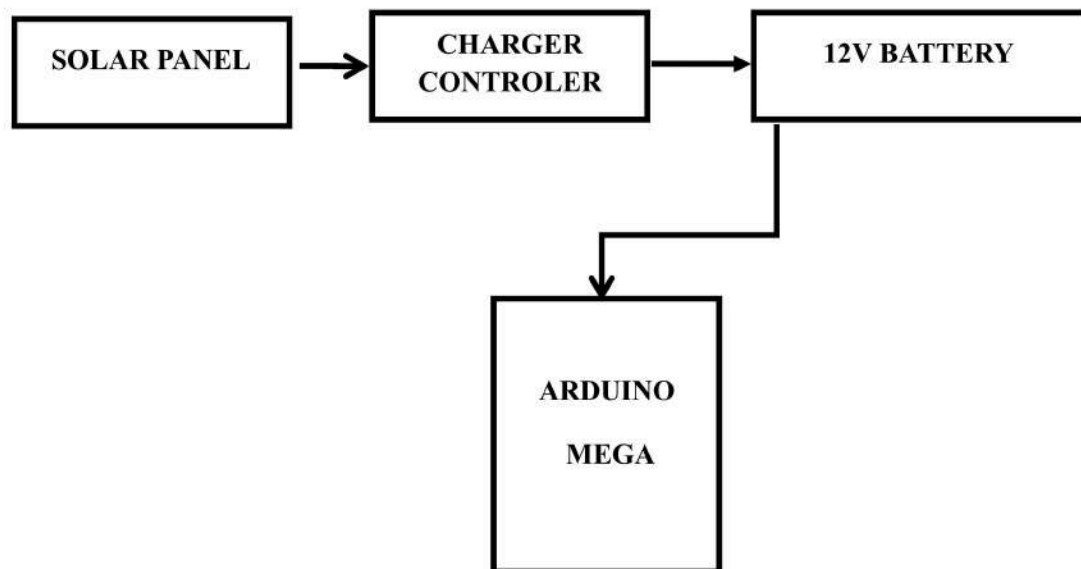


Fig 4.2 Renewable Energy

In this article, we employ the Arduino Mega microcontroller as the central brain of our system. To power the cleaning robot, we utilize a solar panel that harnesses energy from sunlight. This energy is then stored efficiently in a 12V battery through a charger controller. This sustainable power source ensures the continuous operation of our robotic system while reducing its environmental impact.

4.4.2 OBSTACLE & METAL DETECTION

In this article, we have incorporated an ultrasonic sensor for obstacle detection, which serves as a crucial safety feature. Whenever an obstacle is detected, the cleaning robot automatically comes to a halt, ensuring safe navigation. Additionally, a metal detector is employed to identify metallic objects such as nails during the cleaning process, enhancing its thoroughness and safety. The LCD screen displays real-time information, providing users with comprehensive insights into the controller's sensors and the robot's actions, ensuring efficient monitoring and control of the system's operations.

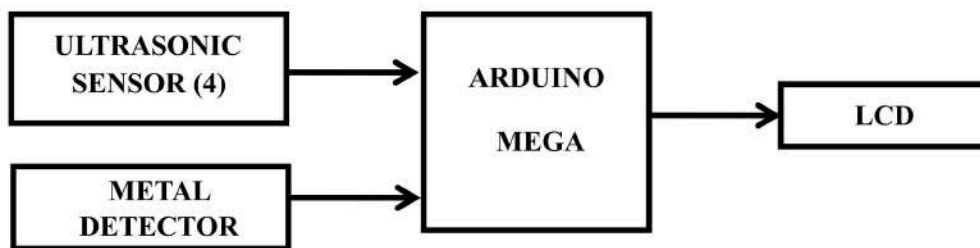


Fig 4.3 Obstacle & Metal Detection

4.4.3 RECEIVED SIGNAL STRENGTH INDICATOR (RSSI)

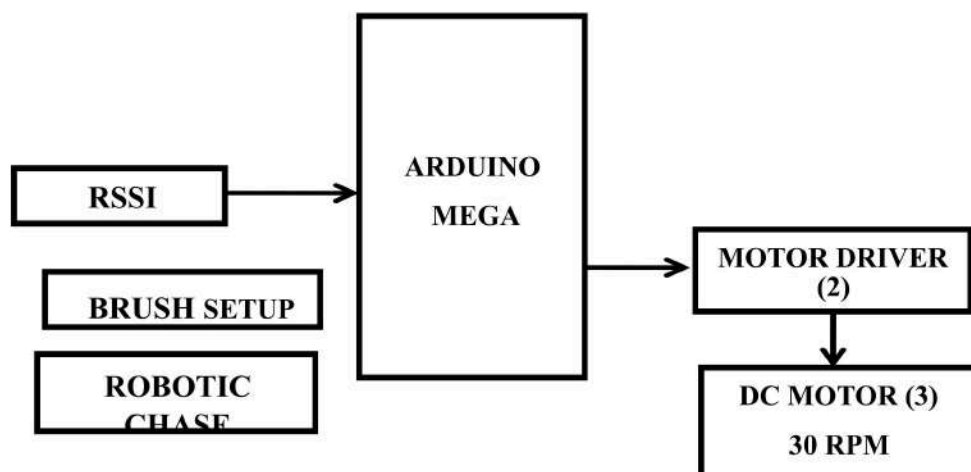


Fig 4.4 Received signal strength indicator (RSSI)

In this module, we leverage the RSSI sensor to precisely determine the robot's location within a defined range. We employ motor drivers to effectively control the DC motors, ensuring seamless movement and navigation. The brush setup, on the other hand, plays a crucial role in the cleaning process, enabling thorough and automated cleaning operations. These components work in synergy, with the RSSI sensor providing location accuracy while the motor drivers facilitate precise motor control. Consequently, the robotic system efficiently maintains cleanliness, making it a versatile solution for a variety of environments and tasks.

4.5 DESCRIPTION AND WORKING OF ARDUINO MEGA

This article operates at its core with an ARDUINO MEGA microcontroller, serving as the central control hub. It harnesses motor drivers to amplify the voltage supplied to a DC motor, enabling precise control of the robot's movement through signals from the microcontroller. The motor's rotation direction, crucial for the robotic chase's mobility, is determined by sending a HIGH input to the motor driver. Additionally, another DC motor comes into play, powering a brush setup essential for the cleaning process. The brush setup intuitively activates as the robot commences its cleaning duties, automatically rotating to ensure a thorough job.

To navigate its environment, the system relies on four ultrasonic sensors, which detect obstacles and guide the robot in four directions: forward, reverse, left, and right. To pinpoint its precise location, an RSSI sensor is employed, adding a layer of accuracy to its navigation capabilities. Furthermore, a Metal detector sensor is integrated to pre-emptively identify the presence of metallic objects, enhancing safety and efficiency.

All critical information, including sensor data and transaction details, is conveniently displayed on an LCD screen, providing real-time insights for effective monitoring and control. Power is primarily sourced from a 12V battery, and in the event of battery depletion, the system seamlessly switches to solar panel-generated power. This transition is meticulously managed by a charger controller, ensuring a continuous and sustainable operation, regardless of the power source.

In essence, this project harmonizes cutting-edge technologies to deliver an adaptable and self-sufficient robotic solution, capable of intelligently maintaining cleanliness while adapting to diverse environments.

4.6 ARDUINO MEGA

Complex projects are best suited for the MEGA 2560. The ideal board for robots and 3D printing applications, it has 54 digital I/O pins, 16 analogue inputs, and more room for your drawing. There is a lot of space and opportunity for your initiatives here.

One such microcontroller board is the Arduino Mega 2560, which is based on the ATmega2560. In addition to a 16 MHz crystal oscillator, a USB connection, a power connector, an ICSP header, a reset button, and 54 digital input/output pins—including 15 that may be used as PWM outputs—it also features 16 analogue inputs and 4 UARTs. It comes with all the necessary components to support the microcontroller; all you need is a USB cable, an AC-to-DC adapter, or a battery to begin. The majority of Uno and Duemilanove/Diecimila-era shield designs are compatible with the Mega 2560 board.

Table 4.1 Arduino Mega

SL .NO	SPECIFICATION	DESCRIPTION AND UNIT
1	MICROCONTROLLER	ATMEGA 2526
2	OPERATING VOLTAGE	5V
3	INPUTVOLTAGE (RECOMMENDED)	7-12V
4	INPUT VOLTAGE (LIMIT)	6-20V
5	DIGITAL I/O PINS	54 (OF WHICH 15 PROVIDE PWM OUTPUT)
6	ANALOG INPUT PINS	16
7	DC CURRENT PER I/O PIN	20 MA
8	DC CURRENT FOR 3.3V PIN	50 MA
9	FLASH MEMORY	256 KB OF WHICH 8 KB USED BY BOOT LOADER
10	SRAM	8 KB
11	EEPROM	4 KB
12	CLOCK SPEED	16 MHZ
13	LED_BUILTIN	13
14	LENGTH	101.52 MM
15	WIDTH	53.3 MM
16	WEIGHT	37 G

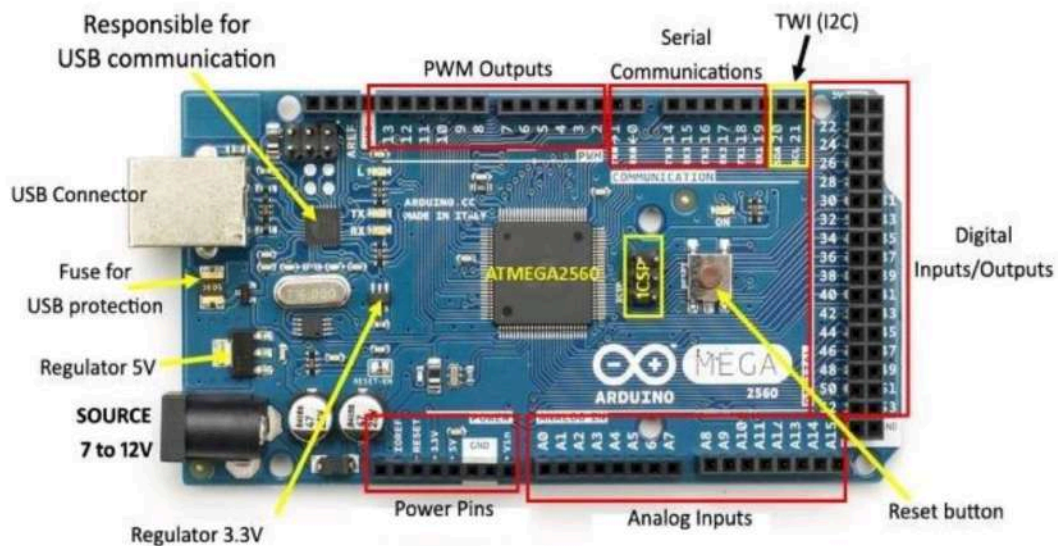


Fig 4.5 Arduino Mega

4.7. HARDWARE

The hardware platform Arduino is open-source. On the Arduino website, you may find the hardware reference designs that are published under a Creative Commons Attribution Share-Alike 2.5 licence. You may also get production and layout files for certain hardware variants here.

Even though the code and designs are open source and protected by copyright, the creators of Arduino have asked that the name not be used for any derivative works without their consent. According to the official policy statement on the usage of the Arduino brand, the project is willing to include other people's work into the official product. A number of commercially available Arduino-compatible items have used names that finish in "-duino" to evade the project name. The 14 digital I/O pins are located on the top, the 6 analogue input pins on the bottom right, and the power

connector on the lower left. This is an early Arduino board with an RS-232 serial interface (upper left) and an Atmel ATmega8 microcontroller chip (black, lower right).

A wide variety of Atmel 8-bit AVR microcontrollers—ATmega8, ATmega168, ATmega328, ATmega1280, and ATmega2560—with different amounts of flash memory, connectors, and features make up the majority of Arduino boards. In 2012, the 32-bit Arduino Due—built on the Atmel SAM3X8E—was unveiled. To make it easier to programme and integrate with other circuits, the boards employ female headers or single- or double-row pins. These can link together with supplementary components called shields. By using an I/C serial bus, it is possible to address each of several, even stacked, shields independently. The majority of boards come with a ceramic resonator or crystal oscillator that operates at 16 MHz and a 5 V linear regulator. For example, the Lilypad runs at 8 MHz and doesn't include an integrated voltage regulator because of certain form-factor constraints.

A boot loader streamlines the process of uploading programmes to the on-chip flash memory of Arduino microcontrollers, which are pre-programmed. The optiboot bootloader is the default on the Arduino UNO. Boards are programmed by connecting them to another computer using a serial connection. A level shifter circuit is available on certain serial Arduino boards for the purpose of converting signals from RS-232 logic levels to TTL levels. The FTDI FT232 and other USB-to-serial converter chips allow current Arduino boards to be programmed using the Universal Serial Bus (USB). In place of the FTDI chip, some boards—like later-model Uno boards—include an AVR chip with USB-to-serial software; this chip may be reprogrammed using its own ICSP connector. The unauthorised Boarduino and the diminutive Arduino Mini are two examples of versions that employ Bluetooth, a removable USB-to-serial adaptor board, or other similar technologies. If you're not using the Arduino IDE, you may still use normal AVR in-system programming (ISP) to programme it using classic microcontroller tools. A genuine Arduino Uno R2 with detailed information on each input and output port

Other circuits can access the majority of the microcontroller's I/O pins through the Arduino board. There are fourteen digital input/output pins on the Diecimila,

Duemilanove, and contemporary Uno, with six of those pins capable of producing pulse-width modulated signals. Additionally, there are six analogue inputs that may double as digital I/O pins. The female 0.1-inch (2.54 mm) headers attach these pins to the top of the board. A number of application shields that connect into existing systems are already on the market. Undersides of the Arduino Nano, Bare Bones Board, and Boarduino boards that are compatible with Arduino may include male header pins that may be plugged into solderless breadboards.

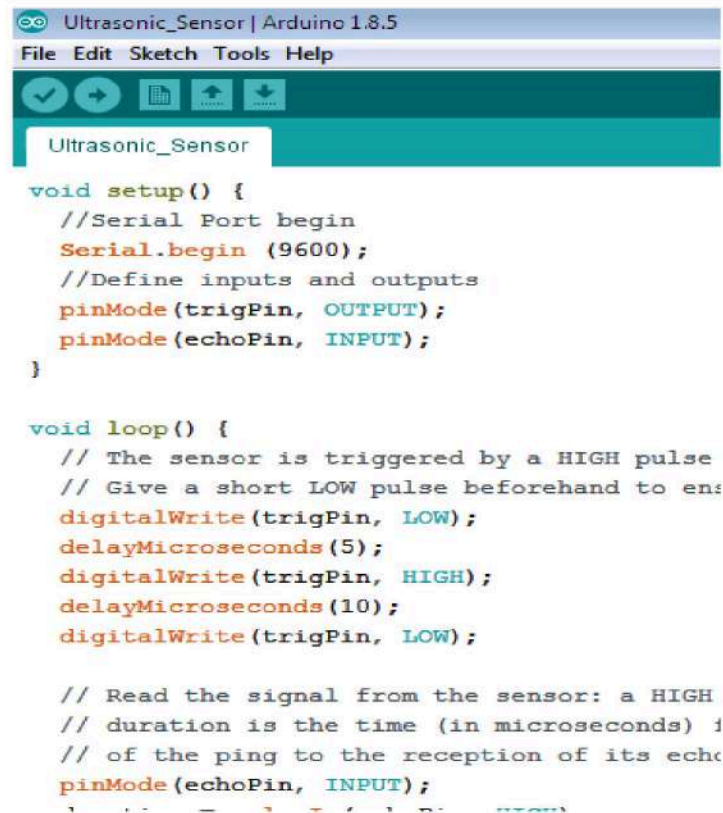
Boards that are compatible with or derived from Arduino are many. Some of them are fully compatible with Arduino and may be used in place of it. To make building buggies and tiny robots easier, several people improve upon the original Arduino by including output drivers; these boards are commonly used in educational settings. There are alternatives that are functionally and electrically identical but have a different shape; these variants may or may not be shield-compatible. There are versions that employ processors that aren't compatible with each other.

4.8 PROGRAMMING IN EMBEDDED C

The Arduino Software Development Environment (IDE) is compatible with the Mega 2560 board. Refer to the reference and tutorials for further information.

Without the need for an external hardware programmer, you may upload fresh code to the ATmega2560 on the Mega 2560 thanks to its preprogrammed boot loader. The original STK500 protocol (included in the C header files) is used for communication.

You can also bypass the boot loader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header using Arduino ISP or similar; see these instructions for details.



```
Ultrasonic_Sensor | Arduino 1.8.5
File Edit Sketch Tools Help

Ultrasonic_Sensor

void setup() {
  //Serial Port begin
  Serial.begin (9600);
  //Define inputs and outputs
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
}

void loop() {
  // The sensor is triggered by a HIGH pulse
  // Give a short LOW pulse beforehand to ens
  digitalWrite(trigPin, LOW);
  delayMicroseconds(5);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  // Read the signal from the sensor: a HIGH
  // duration is the time (in microseconds) i
  // of the ping to the reception of its echo
  pinMode(echoPin, INPUT);
}
```

Fig 4.6 programming code

The ATmega16U2 (or 8U2 in the rev1 and rev2 boards) firmware source code is available in the Arduino repository. The ATmega16U2/8U2 is loaded with a DFU boot loader, which can be activated by:

- *On Rev1 boards:* connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2.
- *On Rev2 or later boards:* there is a resistor that pulling the 8U2/16U2 HWB line to ground, making it easier to put into DFU mode. You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU boot loader). See this user-contributed tutorial for more information

4.9 IMPORTANT COMMAND CODES FOR LCD:

Table 4.2 Command Codes for Lcd

SR.NO.	HEX CODE	COMMAND TO LCD INSTRUCTION REGISTER
1	01	CLEAR DISPLAY SCREEN
2	02	RETURN HOME
3	04	DECREMENT CURSOR (SHIFT CURSOR TO LEFT)
4	06	INCREMENT CURSOR (SHIFT CURSOR TO RIGHT)
5	05	SHIFT DISPLAY RIGHT
6	07	SHIFT DISPLAY LEFT
7	08	DISPLAY OFF, CURSOR OFF
8	0A	DISPLAY OFF, CURSOR ON
9	0C	DISPLAY ON, CURSOR OFF"
10	0E	DISPLAY ON, CURSOR BLINKING
11	0F	DISPLAY ON, CURSOR BLINKING
12	10	SHIFT CURSOR POSITION TO LEFT
13	14	SHIFT CURSOR POSITION TO RIGHT
14	18	SHIFT THE ENTIRE DISPLAY TO THE LEFT
15	1C	SHIFT THE ENTIRE DISPLAY TO THE RIGHT
16	80	FORCE CURSOR TO BEGINNING (1ST LINE)
17	C0	FORCE CURSOR TO BEGINNING (2ND LINE)

4.10 ULTRASONIC SENSOR

Industrial applications of ultrasonic detection often involve the detection of water levels, hidden tracks, and discontinuities in metals, composites, polymers, and ceramics. Since ultrasonic sensors sense sound rather than light, this has become possible by using the physical equations that show how sound waves travel through solid things. A device that uses ultrasonic sound waves to determine the distance to an object is known as an ultrasonic sensor. A transducer is the heart of an ultrasonic sensor, which measures an object's proximity by sending and receiving ultrasonic pulses. Different echo patterns are created when high-frequency sound waves bounce off of surfaces.

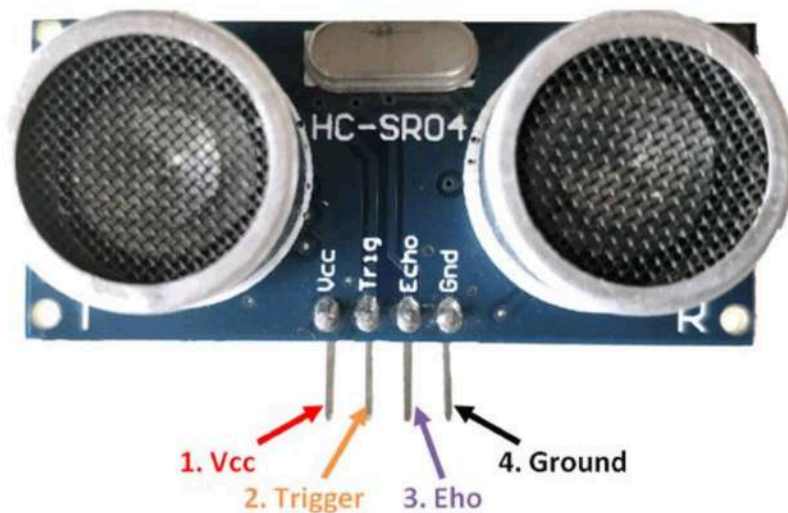


Fig 4.7 Ultrasonic sensor

When an electrical pulse of high voltage is applied to the ultrasonic transducer it vibrates across a specific spectrum of frequencies and generates a burst of sound waves. Whenever any obstacle comes ahead of the ultrasonic sensor the sound waves will reflect back in the form of echo and generates an electric pulse. It calculates the time taken between sending sound waves and receiving echo. The echo patterns will be compared with the patterns of sound waves to determine detected signal's condition.

4.10.1 ULTRASONIC SENSOR PIN CONFIGURATION

Table 4.3 ultrasonic sensor pin configuration

PIN NUMBER	PIN NAME	DESCRIPTION
1	VCC	The VCC pin powers the sensor, typically with +5V
2	Trigger	Trigger pin is an input pin. this pin has to be kept high for 10us to initialize measurement by sending us wave.
3	Echo	“Echo pin is an output pin. this pin goes high for a period of time which will be equal to the time taken for the us wave to return back to the sensor.
4	Ground	This pin is connected to the ground of the system.

4.11 SOLAR PANEL

The source of energy to be independent, there are only a few choices: solar in the form of solar electric panels, hot water panels, and passive heating; wind generators for electric production and windmills for water pumping; and hydro electric generators.”



Fig 4.8 Solar panel

People typically picture huge solar panels, either mounted on rooftops or connected to movable highway signs, when they think about sustainable or alternative energy. The foundation of renewable energy for decades has been these panels, sometimes called photovoltaic modules (or PV modules), which transform sunlight into power. More than a century has passed since the discovery of the Photovoltaic Effect, which explains how solar energy may be transformed into electricity. The adoption of this technology, however, has been slow. Photovoltaics have only recently become a popular alternative to traditional power generation methods.

The first photovoltaic modules were sent into orbit in 1958 to power communication satellites. Solar panels still provide the bulk of the energy needed to run the International Space Station. The conventional use of PV on Earth has been in regions with ample sunlight but no effective electrical power supply. Cabins, recreational vehicles, boats, and small gadgets may often be powered by solar panels in isolated areas where grid access is unavailable. One very inexpensive method of integrating solar power into our daily life is the "grid-tie" solar electric system, which has just begun to gain traction. With the utility grid as a backup, we can now use the solar power that is already accessible.

4.11.1 PRINCIPLE OF SOLAR PANEL

electricity to residences, lodges, and places of business, among other uses: grid-connected systems, sometimes termed utility-interactive, and standalone battery-based systems, which are also referred to as 'off-grid' systems. Get to know both systems well so you can choose the one that's right for you. Solar panels, also known as photovoltaic modules, are, in their most fundamental form, devices that convert sunlight into usable power. Charging batteries and powering common electrical appliances (or "loads") in the home are both possible with this power source and an inverter. In grid-tie systems, PV modules may also be utilised in systems that do not need batteries.

A waterproof backing, tempered glass, and an aluminium frame make up the standard components of photovoltaic modules. The photo-reactive cells, which are typically composed of silicon, are sandwiched between the supporting layers and glasses. A junction box, which could or might not have two wires emerging from it, is located on the module's rear. The electrical terminals may be accessed by opening the junction box, so wires can be added to conduct the generated electricity away from the module if there are no connections. Typically, if there are existing wires, the junction box is sealed and cannot be accessed by the user. The majority of junction boxes are sealed.

Solar power has many potential applications. Using tiny, lightweight PV modules to power portable electronics like music players and mobile phones is one of the easiest. For added portability, these tiny solar panels are finding their way into apparel and bags. These panels have dual functionality: either used singly or connected in a solar array. There are primarily two ways for supplying bigger electrical demands.

4.12 DIRECT CURRENT (DC) MOTOR

An electric motor is responsible for nearly all of the mechanical advancements that we observe in our daily lives. One way to transform energy is by using electric machines. Transforming electrical energy into mechanical energy is what motors are all about. Countless items we rely on on a daily basis rely on electric motors for power. Both alternating current (AC) and direct current (DC) motors are used to describe electric motors. The DC motor and how it operates are the topics of this essay. Moreover, the operation of a gear DC motor. Electric motors that operate on direct current are known as DC motors. Electric motors rely on the principle of electromagnetic to function. A conductor that is carrying current creates its own magnetic field; when exposed to an external magnetic field, it will experience a force that is directly proportional to both the current and the intensity of the external field. It is a tool for transforming mechanical energy into electrical energy. The principle behind it is that a conductor carrying current in a magnetic field will undergo rotation due to the force acting on it.

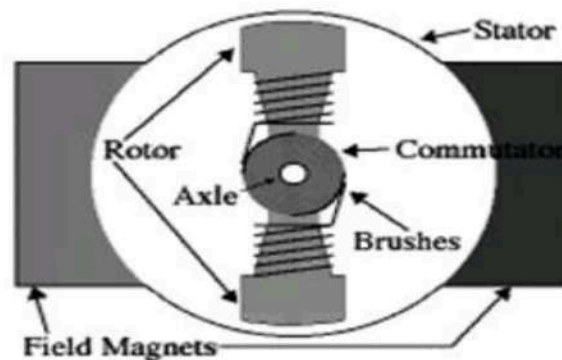


Fig 4.12 DC Motor

The windings that make up the rotor are electrically connected to the commutator. Brushes, commutator contacts, and rotor windings are all designed in such a way that when power is given, the energised winding's polarity is mismatched with the stator's magnets, causing the rotor to move until it is almost parallel to the stator's field magnets.

Once the rotor is in alignment, the brushes will energise the next winding by moving to the next set of commutator contacts. The rotor's magnetic field is flipped during rotation, which causes the current via its windings to reverse direction and drives the rotor to continue revolving.

4.12.1 ADVANTAGES OF DC MOTOR

- "Provide excellent speed control for acceleration and deceleration."
- "Easy to understand design."
- "Simple, cheap drive design."

4.12.2 CONNECTING DC MOTOR WITH MICROCONTROLLER

Direct motor control via microcontrollers is not possible. Therefore, drivers are required to regulate the direction and speed of motors. Connecting microcontrollers to motors is the job of the motor drivers. Because they convert a low-current control signal into a high-current one, motor drivers will function as current amplifiers. The motors are driven by this high-current signal. For simple microcontroller-based motor control, an L293D chip is all that's needed. Inside, you'll find two H-bridge driver circuits.

Two motors may be controlled using this chip. One set of L293D configurations features input 1, input 2, output 1, and an enable pin; the second set features input 3, input 4, output 3, and an additional enable pin.

Here is an example of DC motor which is interfaced with L293D microcontroller.

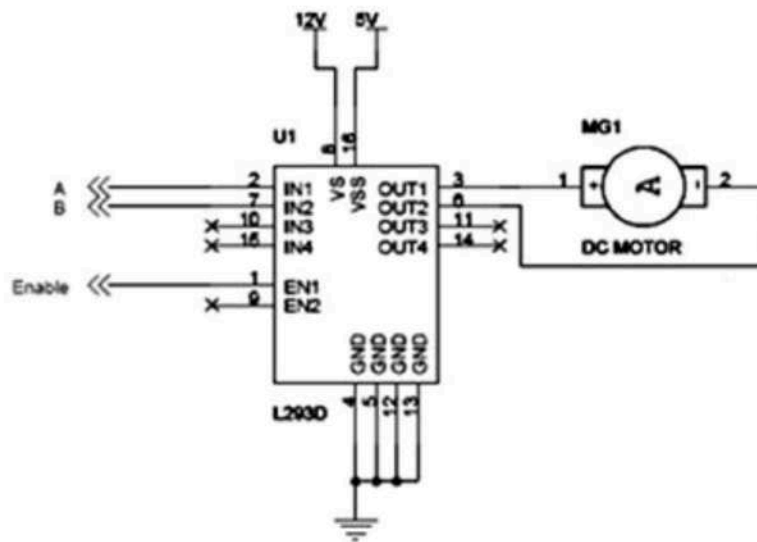


Fig 4.9 DC Motor Interfaced with L293D Microcontroller

The following figure shows that there are two sets of configurations for L293D. One set contains inputs 1, 2, outputs 1, and 2, while the other set has inputs 3, input 4, and outputs 3, and 4.

- It follows that pins 3 and 6 will likewise be high if pins 2 and 7 are. To make the motor turn in a forward manner, set enable 1 and pin 2 to high while leaving pin 7 low.
- The motor will spin anticlockwise if enable 1 and pin 7 are both high and pin 2 is low.

Even in modern times, dc motors continue to find numerous uses, from tiny toys and disc drives to massive steel rolling mills and paper presses.

4.12.3 DC MOTOR EQUATIONS

Magnitude of flux experienced is,

$$F = BIl$$

Where, B- Flux density due to flux produced by field windings

l- Active length of the conductor,

I-Current passing through the conductor.

As the conductor rotates, an EMF is induced which acts in a direction opposite to the supplied voltage. It is given as

$$E_b = \frac{\phi PNZ}{60A} \longrightarrow 1$$

Where, ϕ - Flux due to the field windings,

P- Number of poles,

A-a constant,

N – Speed of the motor,

Z- Number of conductors.

The supply voltage, $V = E_b + I_a R_a$

The torque developed is

$$T_a = \frac{0.159 \phi I_a P Z}{A} \longrightarrow 2$$

Thus, the torque is directly proportional to the armature current.

Also speed varies with armature current, hence indirectly torque and speed of a motor are dependent on each other.

For a DC shunt motor, speed remains almost constant even if torque increases from no load to full load.”

For a DC series motor, speed decreases as torque increases from no load to full load.

Thus, torque can be controlled by varying the speed. Speed control is achieved either by,

- The flux control method involves regulating the current through a field winding in order to alter the flux. This technique allows for control of speeds greater than their rated speeds.
- Armature Voltage Control – Provides speed control below its normal speed.
- Supply Voltage Control – Provides speed control in both directions.

4.13 METAL DETECTOR SENSOR



Fig 4.10 Metal detector circuit RC-A-354

One way to find metals without actually touching them is with a metal detector. The idea of inductive sensing for metal detection is presented in this study. A metal's presence may change an inductor's inductance value; this is the fundamental idea. This prototype is an updated inductance metre that can detect a change in inductance and then activate an output.

A simple coil or inductor can have its unknown inductance measured with the use of an inductance metre. A tank circuit, consisting of a parallel connection between an inductor and a capacitor, is utilised in the project. Any metal in close proximity to the tank circuit

will cause the natural resonating frequency to change. An Arduino board, a simple prototyping platform, was used to build the prototype. The prototype is constructed on a breadboard that contains an inductor. It is designed to sound an alert through a loudspeaker if any metal is brought close to the inductor.

4.13.1 WORKING CONCEPT OF METAL DETECTOR SENSOR

A magnetic field is created around the coil whenever a current flows through it. Additionally, an electric field is produced by a change in the magnetic field. Now, as a result of this electric field, a voltage develops across the coil, which goes against the change in the magnetic field. This is how a coil produces inductance, which implies that the voltage created goes against the rise in current, according to Faraday's law. Any metal that comes into contact with the coil causes a change in its inductance. Which metals undergo these changes in inductance is material dependent. It's lower for metals that aren't magnetic and higher for iron and other ferromagnetic materials. The inductance value varies greatly with the coil's core. There will be no solid core in the air-cored inductors, as seen in the image below. Simply said, they are airborne coils. When an inductor produces a magnetic field, nothing or air acts as the medium through which the field flows. There is relatively little value in the inductances of these inductors. Use these inductors when you require values that are a few microHenry. These are not appropriate for levels higher than a few milliHenry. You may observe a ferrite-core inductor in the image below. The inductance value of this Ferrite Core inductor is quite high.

When you bring a metal object close to the coiled coil of this air cored inductor, the metal object serves as the core for the inductor. The inductance of the coil is altered or amplified significantly when this metal serves as its core. When compared to the LC circuit without the metal component, the total reactance or impedance varies significantly due to the abrupt rise in coil inductance. In order to detect metals, we need to determine the coil's inductance in this Arduino Metal Detector Project. Thus, we have utilised the LR circuit, which stands for "Resistor-Inductor Circuit," to accomplish this. A coil with about 20 turns or windings with a diameter of 10 cm was utilised in this circuit. We wound the wire around an empty roll of tape to create the coil.

To keep our metal detector project running well, we utilised an Arduino Nano. As an indication for metal detection, a buzzer and an LED are utilised. Metal detection uses a coil and capacitor. To further lower the voltage, a signal diode is employed. A resistor to control the amount of current that can flow to the Arduino pin

4.14 RECEIVED SIGNAL STRENGTH INDICATOR (RSSI)

one way to find out how effectively your device can pick up a signal from a router or access point is to look at the "Received Signal Strength Indicator," or RSSI. If you want to know if your wireless signal is strong enough to establish a reliable connection, this number is helpful. Keep in mind that the transmit power from a router or access point is different from the RSSI number as the former is derived from the Wi-Fi card of the client device (hence "received" signal strength). Signal strength is represented by both dBm and RSSI, which are distinct units of measurement. A relative index, RSSI, compares to an absolute figure, dBm, which represents power levels in milliwatts.

The relative strength of a received signal as perceived by a client device is known as RSSI; nevertheless, this metric does not have an absolute value. Each chipset manufacturer can specify their own RSSI scale; for instance, Cisco uses a 0-100 scale while Atheros uses 0-60. This is specified in the IEEE 802.11 standard, a large book that details how WiFi equipment should be manufactured. The specification allows for RSSI values ranging from 0 to 255. Although the manufacturer has complete control over the RSSI (that's why it's a relative index), a higher RSSI value (RSSI_Max) is indicative of a better signal. Given that RSSI differs substantially among chipset makers. The relative intensity of the received signal in a wireless environment, expressed in arbitrary units, is known as RSSI in an IEEE 802.11 system. Following the antenna and any potential cable loss, the RSSI indicates the power level received by the receiving radio. Consequently, a greater RSSI value indicates a stronger signal. Therefore, the closer the RSSI value is to 0, when expressed negatively (e.g., -100), the stronger the received signal.

A wireless networking card's inbuilt RSSI can be used to detect when the channel's radio energy level drops below a specific threshold, allowing the card to transmit a CTS signal. A data packet can be transmitted once the card has been cleared for transmission. When a user uses a tool like Wireshark, Kismet, or Insider to measure the signal strength of a wireless network, they will most likely see an RSSI result. For instance, Cisco Systems cards can only have an RSSI number between 0 and 100, and they'll report 101 distinct power levels. Atheros makes another well-liked Wi-Fi chipset. No value between 0 and 127 (0x7f) will be returned by an Atheros-based card's RSSI, with 128 (0x80) being an invalid value.

No one physical parameter is known to have a consistent correlation with the RSSI measurement. Unfortunately, the 802.11 standard doesn't specify how the RSSI value relates to the power level in milliwatts or decibels with respect to one milliwatt. Both the real power (in milliwatts or decibels) and the range of RSSI values (from zero to the maximum) are provided by the vendors and chipset makers. The accuracy, granularity, and range are their own. The 802.11 RSSI metric is nuanced in that it is sampled at the preamble step of receiving an 802.11 frame, rather than the entire frame. Using RSSI for coarse-grained position estimations was possible for researchers as early as 2000. These results were later replicated in more recent study with more sophisticated methods. That being said, RSSI readings aren't usually precise enough to pinpoint the exact spot. Since it is accessible in nearly all wireless nodes and does not necessitate any extra hardware, RSSI remains the most practical indication.

4.14.1 RECEIVED CHANNEL POWER INDICATOR

Received channel power indicator (RCPI) has mostly supplanted 802.11 RSSI. RCPI is a specified absolute metric for measuring the received radio frequency power in a specific channel during the preamble and the complete received frame; it is an 802.11 measure. Since 802.11 is the only protocol that uses RCPI, IEEE 802.11k-2008 imposes certain accuracy and resolution requirements on it. In order to set up a connection for communication between wireless nodes, it is required to evaluate the received signal strength. On the other hand, unlike measures like transit time measurement (time of arrival), power level metrics like RCPI often cannot remark on the network quality.

One microcontroller that Espressif Systems created is known as the ESP8266. A self-contained Wi-Fi networking solution, the ESP8266 can run its own programmes and serves as a bridge between Wi-Fi and current micro controllers. This module has a wide variety of pin-outs and an integrated USB port. Similar to Arduino, the NodeMCU devkit may be easily flashed by connecting it to a laptop via a micro-USB connection. In addition, it works well with breadboards right away.

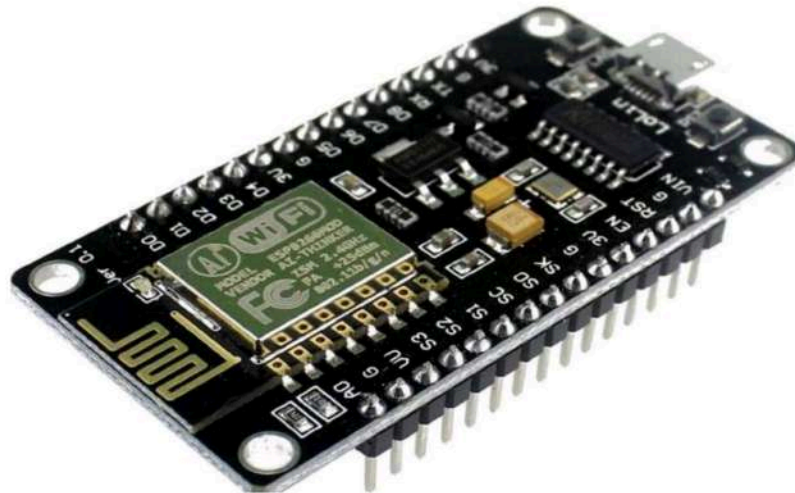


Fig 4.11 ESP-12E BASED NODEMCU

AI-thinker Team created the ESP-12E Wi-Fi module. In a compact form factor, the Tensilica L106 module has the ESP8266 core processor, a 32-bit microcontroller with 16-bit short mode, support for 80 MHz and 160 MHz clock speeds, RTOS functionality, integrated Wi-Fi MAC/BB/RF/PA/LNA, and an on-board antenna. This module is compatible with the whole TCP/IP protocol stack and the standard IEEE802.11 b/g/n agreement. Connecting new networking devices or creating a standalone network controller are both possible with the help of the available modules. For builders of mobile platforms with little space and power, ESP8266 is a high-integration wireless system on a chip (SOC). It offers the most cost-effective and space-efficient way to integrate Wi-Fi into existing systems or run independently as an application.

4.15 LCD PIN DIAGRAM

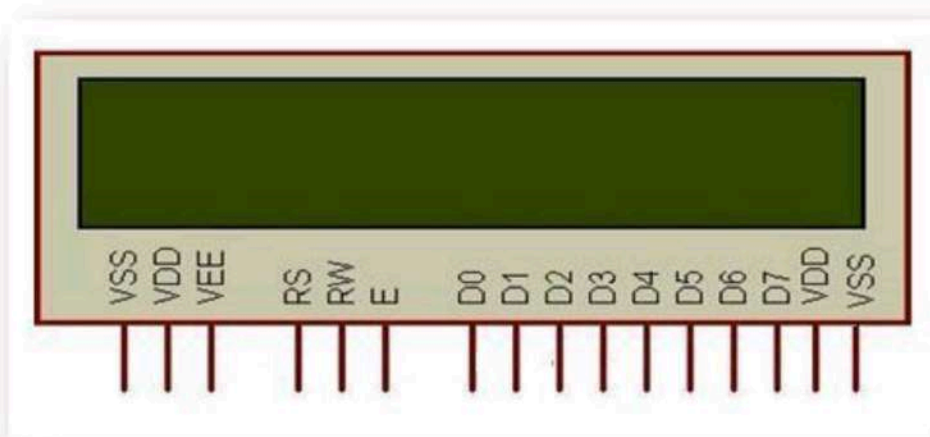


Fig 4.12 Pin Diagram of LCD

Everywhere we look, we can see LCD monitors. Any device that can show the time, be it a computer, calculator, TV, mobile phone, or digital watch, uses a display. Electronic display modules that employ liquid crystal to generate a readable image are known as liquid crystal displays (LCDs). Projects frequently make use of the 16x2 LCD display, a rudimentary module. A display with 16 characters per line on two lines is given by the 162 ratio. A 5x7-pixel matrix displays each character in this LCD.

It is not hard to generate bespoke characters on LCD. Understanding the LCD chip controller and custom generated random-access memory (CG-RAM) is necessary. A Hitachi HD4478 controller is found in the majority of LCDs. When it comes to creating unique characters, CG-RAM is king. Once specified in the code, it saves the custom characters. The 64-byte CG-RAM capacity allows for the creation of eight characters simultaneously. There are eight bytes in a character.

4.15.1 PIN DESCRIPTION FOR LCD

Table 4.15.1 Pin Description for Lcd

PIN NO	FUNCTION	NAME
1	GROUND (0V)	GROUND
2	SUPPLY VOLTAGE; 5V (4.7V – 5.3V)	VCC
3	CONTRAST ADJUSTMENT; THROUGH A VARIABLE RESISTOR	VEE
4	SELECTS COMMAND REGISTER WHEN LOW; AND DATA REGISTER WHEN HIGH	REGISTER SELECT
5	LOW TO WRITE TO THE REGISTER; HIGH TO READ FROM THE REGISTER	READ/WRITE
6	SENDS DATA TO DATA PINS WHEN A HIGH TO LOW PULSE IS GIVEN	ENABLE
7	8-BIT DATA PINS	DB00
8	DATA PIN 01	DB01
9	DATA PIN 02	DB02
10	DATA PIN 03	DB03
11	DATA PIN 04	DB04
12	DATA PIN 05	DB05
13	DATA PIN 06	DB06
14	DATA PIN 07	DB07
15	DATA PIN 08	DB08
16	BACKLIGHT V _{CC} (5V)	LED+
17	BACKLIGHT GROUND (0V)	LED-

CHAPTER: 5

RESULTS AND DISCUSSION

5.1 RESULT

In this article, we successfully designed and built a solar-powered smart floor cleaner with the following components: HC05 Bluetooth module, L298 motor driver, ultrasonic sensor, Arduino Uno, DC motor, solar panel, and battery. This innovative cleaning solution combines renewable energy, advanced robotics, and wireless control to provide a versatile and ecofriendly cleaning experience.

5.1.1 KEY FEATURES AND ACHIEVEMENTS

- i. **Solar Power Integration:** It is successfully integrated a solar panel into the floor cleaner, harnessing renewable energy to power the device. This feature not only reduces the environmental impact but also ensures prolonged cleaning operation without relying on conventional energy sources.
- ii. **Bluetooth Control:** The HC05 Bluetooth module enables convenient wireless control of the floor cleaner. Users can operate it remotely via a dedicated mobile app or a remote-control device, enhancing usability and flexibility during cleaning sessions.
- iii. **Obstacle Detection and Avoidance:** It implemented an ultrasonic sensor to detect obstacles in the floor cleaner's path. When obstacles are detected, the floor cleaner intelligently adjusts its course to avoid collisions, improving efficiency and safety.
- iv. **Arduino Uno Brain:** The Arduino Uno served as the central processing unit for the system. It effectively managed sensor data, controlled the DC motor through the L298 motor driver, and facilitated seamless Bluetooth communication for remote operation.

- v. **Efficient Cleaning:** The DC motor, combined with custom cleaning attachments, demonstrated efficient cleaning capabilities. The floor cleaner effectively collected dust and debris, ensuring a cleaner living space.
- vi. **Energy Management:** The integration of a battery allowed for energy storage, ensuring uninterrupted operation even when sunlight is unavailable. The system effectively managed energy from the solar panel and battery to power the floor cleaner.

5.2 DISCUSSION

Another challenge is the need for further development in the areas of navigation and obstacle avoidance. Some solar power floor cleaning robots can still have difficulty navigating complex environments or avoiding obstacles.

Overall, the results of studies and pilot projects to date suggest that solar power floor cleaning robots have the potential to provide a number of benefits. However, further development is needed to address some of the challenges associated with these robots, such as their cost and the need for improved navigation and obstacle avoidance capabilities.

Here are some additional thoughts on the results and discussion of solar power floor cleaner robots:

- i. Solar power floor cleaning robots are still in their early stages of development, but they have the potential to revolutionize the way we clean floors.
- ii. These robots offer a number of advantages over traditional methods of floor cleaning, including increased efficiency, reduced costs, improved hygiene, and reduced environmental impact.
- iii. However, there are also some challenges that need to be addressed before solar power floor cleaning robots can be widely adopted, such

as their cost and the need for further development in the areas of navigation and obstacle avoidance.

- iv. As the technology continues to develop, we can expect to see solar power floor cleaning robots become more affordable, intelligent, and efficient. We may also see robots that are capable of performing other tasks, such as vacuuming and dusting.

Overall, the future of solar power floor cleaning robots is bright. These robots have the potential to make our lives easier and more sustainable.

5.3 FABRICATION OF SOLAR FLOOR CLEANER ROBOT

The outcome of a solar-powered floor cleaner robot could be quite positive in terms of environmental impact and efficiency. By harnessing solar energy, the robot can operate without relying on traditional energy sources, reducing its carbon footprint. Additionally, solar power can provide a sustainable and renewable energy source for prolonged operation, making the robot more cost-effective in the long run. Overall, such a robot could contribute to cleaner floors while promoting environmental sustainability.



Fig 5.1 Solar Power Floor Cleaner Robot

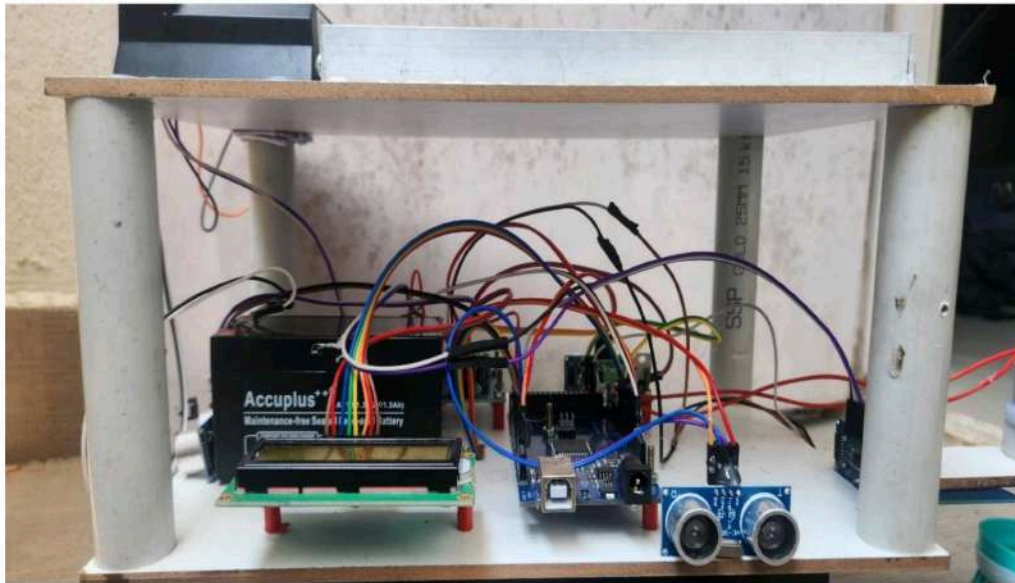


Fig 5.1 Solar Power Floor Cleaner Robot

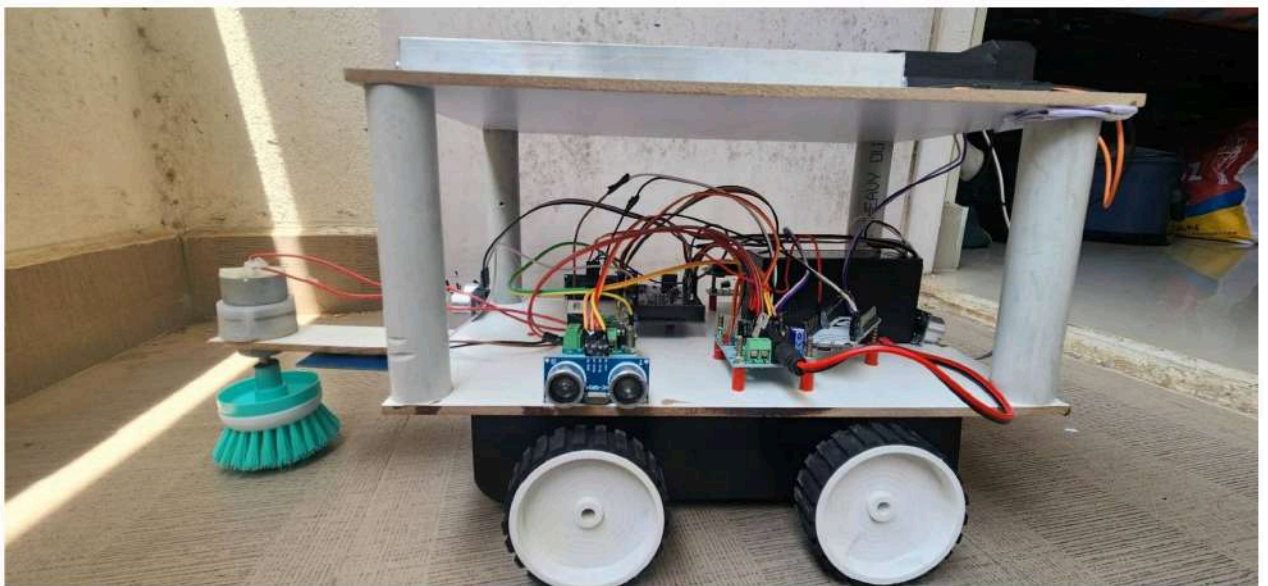


Fig 5.1 Solar Power Floor Cleaner Robot

CHAPTER: 6

CONCLUSION

6.1 CONCLUSION

In conclusion, the development of a solar-powered floor cleaner integrated with components such as the Bluetooth module, motor driver, ultrasonic sensor, Arduino Uno, DC motor, solar panel, and battery represents a remarkable fusion of technology and sustainability. This project accomplishes several key objectives and offers a host of benefits:

- i. **Sustainability:** By harnessing energy from the sun through the solar panel, this floor cleaner operates in an eco-friendly manner, reducing dependence on conventional power sources and minimizing its carbon footprint.
- ii. **Advanced Control:** The integration of the Bluetooth module and Arduino Uno provides remote control capabilities, enabling users to manage the floor cleaner from a distance, enhancing convenience and adaptability.
- iii. **Efficient Cleaning:** The DC motor, under precise control of the motor driver and Arduino Uno, ensures effective and efficient cleaning. Additionally, the inclusion of an ultrasonic sensor enables obstacle detection and avoidance, ensuring thorough cleaning without collisions or interruptions.
- iv. **Energy Management:** The battery serves as an essential component, storing solar energy for continued operation during low-light conditions or at night. It optimizes power usage and ensures uninterrupted cleaning sessions.

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