



# DESIGN AND FABRICATION SOLAR POWERED AGRICULTURAL SPRAYER ROBOT

Submitted By

GORSA DINESH	236D5A0314
GOLLAVILLI HEMANTH KUMAR	236D5A0312
JAGARAPU DILLEEP	236D5A0318
JERRIPOTHULA RAMUNAIDU	236D5A0321
ADARI VAMSI	236D5A0301

Under the esteemed guidance of

**Mr. M. PADMANABHAM M.Tech (Ph.D)**

**Assistant professor**

**HOD OF MECHANICAL DEPARTMENT**

## ABSTRACT

Conventional agricultural pesticide and fertilizer spraying exposes farm workers to harmful chemicals, requires substantial manual labor, and is constrained by the physical endurance of the operator. This project presents the design and fabrication of a *Solar Powered Agricultural Sprayer Robot* that eliminates direct human exposure to agrochemicals through remote Bluetooth wireless control while operating entirely on renewable solar energy.

The system is built around an Arduino UNO microcontroller that receives directional commands (Forward, Backward, Left, Right, Stop, Spray ON/OFF) from an Android smartphone via an HC-05 Bluetooth module over UART serial communication. Two L298N dual H-bridge motor driver modules independently control four 12V DC gear motors mounted in a four-wheel-drive configuration for robust terrain traversal across uneven field surfaces. A 1-channel 5V relay module, driven by an Arduino digital output pin, switches the 12V DC submersible pump motor that pressurizes the spray nozzle system. A 20W monocrystalline solar panel charges the 12V/7Ah SLA battery through a PWM solar charge controller (SCC), providing self-sustaining field operation during daylight hours.

Prototype testing confirmed reliable Bluetooth range of 8–10 m in open field conditions,

successful directional control on soil and grass surfaces, spray coverage width of approximately

1.2 m at 0.5 m nozzle height, and continuous operation of 4–5 hours on a fully charged 12V/7Ah battery. This documentation covers complete mechanical design, circuit schematics, Arduino firmware, Android app configuration, performance test results, and future enhancement roadmap.

## CHAPTER – 1

### INTRODUCTION

#### **1.1 Background and Motivation**

in developing nations, and the timely application of pesticides, herbicides, and liquid fertilizers is critical to achieving adequate crop yields. Conventional spraying methods require farm workers to carry heavy backpack sprayers or push wheeled sprayer tanks through fields, directly exposing themselves to toxic agrochemicals through inhalation, skin contact, and accidental ingestion.

According to the World Health Organization (WHO), approximately 3 million acute pesticide poisoning cases occur globally every year, predominantly among agricultural workers in low-income countries. Beyond health hazards, manual spraying is physically exhausting, slow (coverage rates of 0.1–0.3 ha/hr by one person), and highly dependent on operator skill for uniform chemical application.

The emergence of low-cost microcontrollers such as the Arduino UNO, ubiquitous smartphone Bluetooth connectivity, and affordable solar energy harvesting technology creates a compelling opportunity to develop a ground-based robotic sprayer that can be remotely operated from a safe distance, powered entirely by solar energy, and fabricated at a fraction of the cost of commercial agricultural robots.

This project is directly motivated by these converging factors: the clear public health need to reduce agrochemical exposure, the engineering opportunity offered by mature low-cost components, and the agricultural need for affordable precision application technology accessible to smallholder farmers.

#### **1.1 Problem Statement**

**Problem Statement:** Design and fabricate a solar-powered four-wheel-drive agricultural sprayer robot controlled wirelessly via HC-05 Bluetooth module and Arduino UNO, capable of navigating crop fields in forward, backward, left, and right directions on command from an Android smartphone application, and activating a pump-driven spray system on demand, thereby eliminating direct human exposure to agrochemicals during spraying operations.

The specific problems addressed:

- Farmer health risk from direct chemical exposure during spraying.
- High labour intensity and physical fatigue of manual field spraying.
- Non-uniform chemical application due to manual technique variability.
- Grid-power dependence limiting deployment in remote farm locations.
- High cost of existing commercial agricultural robots (>\$5,000).

## 1.2 Objectives of the Project

### *Primary Objectives*

1. Design and fabricate a 4WD robot chassis suitable for traversal of unpaved agricultural terrain.
2. Integrate two L298N dual H-bridge motor drivers to independently control four 12V DC gear motors for directional mobility.
3. Implement HC-05 Bluetooth UART communication between the Arduino UNO and an Android smartphone for wireless remote control.
4. Develop Arduino firmware to decode Bluetooth commands (F, B, L, R, S, P, Q) and execute corresponding motor and pump actions.
5. Integrate a 1-channel relay module to switch the 12V submersible pump motor on/off via Bluetooth command.
6. Design a 20W solar panel charging system with SCC and 12V/7Ah SLA battery for self-sustaining field operation.
7. Achieve reliable Bluetooth control range of  $\approx 8$  m and continuous operation of  $\approx 4$  hours on a full charge.

### *Secondary Objectives*

- Document complete system design, wiring schematics, firmware code, and test data.
- Evaluate spray coverage uniformity and nozzle performance.
- Assess economic viability relative to commercial alternatives.

## 1.3 Scope and Limitations

### Scope

The project covers: mechanical chassis fabrication; electronic hardware design including motor driver, relay, and Bluetooth wiring; Arduino firmware; Android app configuration; solar power system design; laboratory and field performance testing on flat and moderately uneven soil/grass surfaces.

**Limitations**

- Bluetooth range limited to approximately 8–10 m line-of-sight (standard HC-05 Class 2).
- No autonomous navigation; requires continuous operator input via smartphone.
- Designed for relatively flat terrain (slope  $\leq 15^\circ$ ).
- Tank capacity limited to 5 liters in current prototype, suitable for small plot demonstrations.
- No real-time video feedback in the current version.

**1.5 Applications of the System**

Application	Description
<b>Small-Scale Farms</b>	Wireless-controlled spraying on 0.1–1 ha plots without chemical exposure.
<b>Greenhouse Spraying</b>	Compact robot navigates greenhouse rows for pest control.
<b>Nursery Horticulture</b>	& Gentle, precise spray for seedling nurseries.
<b>Lawn & Turf Management</b>	fertilizer application on sports grounds.
<b>Research Plots</b>	Controlled application for agricultural field experiments.
<b>Disaster/Emergency Use</b>	mote deployment for decontamination spraying.
<b>Educational Platform</b>	Teaching embedded systems, IoT, and robotics concepts.

FIG 1.5 APPLICATION OF THE SYSTEM

## **LITERATURE REVIEW**

### **2.1 Agricultural Spraying Techniques**

Agricultural chemical application methods have evolved from primitive hand-held sprinklers to sophisticated airborne drone systems. The primary spraying mechanisms are categorized below.

#### **2.1.1 *Knapsack/Backpack Sprayers***

The most prevalent method in smallholder farming, the knapsack sprayer (15–20 L tank) is carried on the back and manually pressurized by a hand pump lever. The operator walks the field and directs the spray lance manually. Despite their low cost (~\$15–40), these devices expose operators to chemical drift and require significant physical effort.

#### **2.1.2 *Tractor-Mounted Boom Sprayers***

Large-scale farms use tractor-mounted sprayers with boom widths of 12–36 m achieving coverage rates of 50–120 ha/day. However, the equipment cost (\$8,000–80,000), fuel consumption, and soil compaction from the heavy tractor make them entirely unsuitable for small-plot or smallholder farming.

#### **2.1.3 *Unmanned Aerial Vehicle (UAV/Drone) Sprayers***

Agricultural spray drones (DJI Agras series, for example) have gained traction for large plantation applications. They offer high speed coverage but at very high capital cost (\$15,000–80,000), require trained pilots, CAA/DGCA regulatory approvals, and have limited payload (10–30 L) and battery endurance (10–15 min per charge). They are impractical for subsistence-level farming.

#### **2.1.4 *Ground-Based Robotic Sprayers***

Ground robots for precision spraying have been the subject of active research since the early 2000s. They offer the advantages of close-range application (reducing chemical drift), heavy payload capacity, and no altitude-related regulations. Battery or solar-powered ground robots are emerging as a cost-effective middle ground between manual and aerial approaches.

## 2.2 Review of Existing Sprayer Robot Designs

Reference	Controller	Communicatio	nDrive	Solar	Key Feature
Bharat et al. (2019)	Arduino+L293D	Bluetooth	2WD	No solar	8m BT range
Reddy et al. (2020)	Raspberry Pi	WiFi	4WD	Solar	Camera feedback
Kumar & Singh (2021)	Arduino+L298N	RF 433MHz	4WD	No solar	Limited range

Table 2.2: Comparison of existing agricultural sprayer robot designs.

## 2.3 Bluetooth Communication in Agricultural Robots

Bluetooth serial communication (SPP – Serial Port Profile) using the HC-05 module is widely adopted in Arduino-based mobile robot projects due to its ease of use, low cost (~\$3–6), and direct UART interface compatibility with the Arduino Serial library. The HC-05 pairs with Android devices running simple Bluetooth serial terminal apps such as 'Bluetooth RC Controller', 'Arduino Bluetooth Controller', or custom MIT App Inventor applications.

Key literature findings:

- HC-05 operating at 9600 baud provides sufficient command throughput for real-time robot control (latency < 50 ms within 10 m range).
- Single-character command encoding (e.g., 'F' = forward, 'B' = back) minimizes packet size and reduces the probability of command loss.
- Android Bluetooth SPP apps are readily available on Google Play Store, enabling no-code operator interface setup.
- HC-05 Class 2 Bluetooth (2.4 GHz ISM band) achieves 8–15 m range depending on obstacles; line-of-sight range is typically 10 m at 0 dBm output power.

## 2.4 Solar Energy for Agricultural Equipment

Solar photovoltaic technology has matured significantly, with monocrystalline silicon panels achieving efficiencies of 17–22% at costs below 0.50/W at the module level. A 20W panel (peak power at 1000 W/m<sup>2</sup> irradiance, STC) generates approximately 80–100 Wh per day under typical Indian/tropical conditions (4–5 peak sun hours per day).

Battery charging considerations:

- A 12V/7Ah SLA battery has a usable capacity of approximately 50–60 Wh (80% DoD limit). A 20W panel fully recharges the battery in approximately 4–6 hours of good sunlight, well within a single day's solar window.
- PWM Solar Charge Controllers (SCC) regulate the panel output to the battery's charging voltage profile: bulk (14.4–14.7V), absorption, and float (13.8V), preventing overcharge and extending battery life.
- Hybrid operation (solar + battery) is standard: the robot operates from battery while the panel simultaneously trickle-charges or supplements the supply.

### Motor Control and H-Bridge Drivers

The L298N dual H-bridge motor driver IC is the industry standard for Arduino-based motor control in educational and prototype applications. Each L298N chip contains two full H-bridges capable of driving motors up to 2A per channel (4A peak), suitable for the 12V DC gear motors used in this project.

#### *H-Bridge Operation Principle*

An H-bridge circuit consists of four switching elements (transistors or MOSFETs) arranged in an 'H' shape around the motor. By controlling which diagonal pair of switches is ON, the polarity of voltage across the motor is reversed, enabling bidirectional rotation. The L298N module includes the H-bridge transistors, a logic-level translator for Arduino 5V compatibility, built-in flyback diodes (or external provision), and an enable (ENA/ENB) pin for PWM speed control.

#### *L298N Truth Table (per channel)*

IN1	IN2	Motor Action
LOW	LOW	Stop (motor coasts)
HIGH	LOW	Forward (CW rotation)
LOW	HIGH	Backward (CCW rotation)
HIGH	HIGH	Brake (both terminals HIGH)

*Table 2.4: L298N H-bridge truth table.*

## 2.5 Research Gaps and Project Justification

- Most published Arduino Bluetooth sprayer designs use 2WD; 4WD provides superior traction on soft agricultural soil and is rarely implemented with full documentation.
- Solar integration with robot sprayers is reported but rarely documented with charge controller selection, wiring, and battery sizing calculations.
- Complete annotated Arduino firmware and Android app setup instructions are missing from most published works.
- Economic analysis benchmarking prototype cost against commercial alternatives is typically absent.

### INTRODUCTION – 3

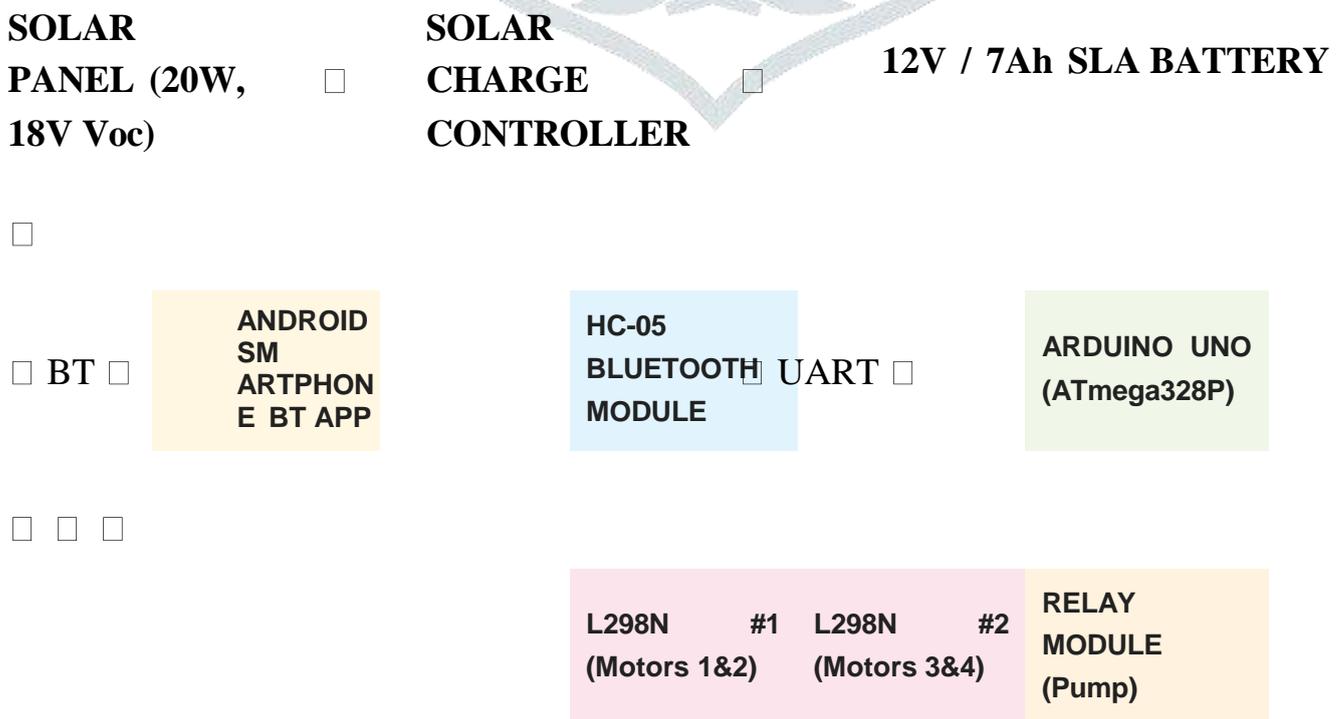
#### SYSTEM DESIGN AND METHODOLOGY

##### 3.1 Overall System Architecture

The Solar Powered Agricultural Sprayer Robot is organized as a five-subsystem mechatronic platform:

1. **Mechanical Platform:** 4WD robot chassis, spray tank, nozzle assembly.
2. **Power Subsystem:** Solar panel, charge controller, 12V battery, power distribution.
3. **Motion Control:** Arduino UNO + 2× L298N motor drivers + 4 gear motors.
4. **Spray Subsystem:** 1-channel relay module + 12V submersible pump + spray nozzle.
5. **Communication:** HC-05 Bluetooth module + Android smartphone app.

##### *Block Diagram Description*

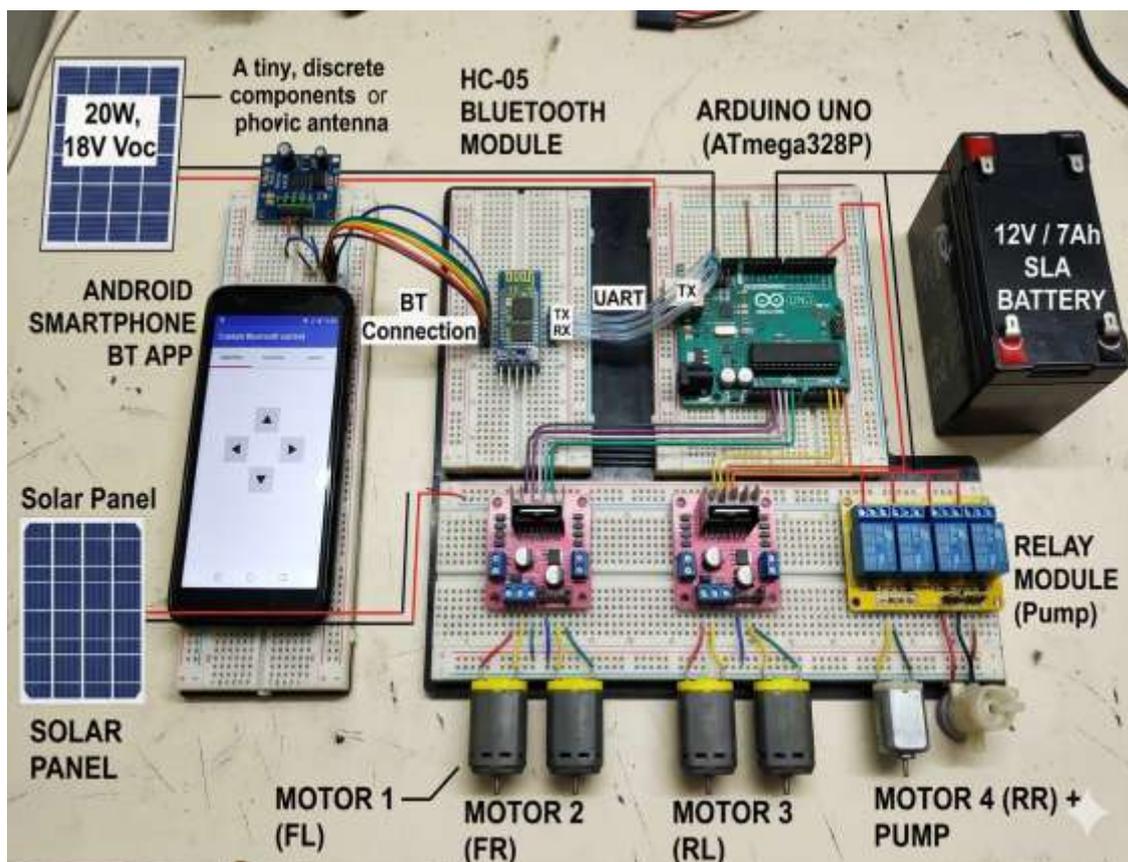


**Motor 1 (FL)**

**Motor 2 (FR) Motor 3 (RL) Motor 4 (RR) + PUMP**

*Figure 3.1: System architecture block diagram (FL=Front-Left, FR=Front-Right, RL=Rear-Left, RR=Rear-Right).*

## Circuit diagram



*Figure 3.2 – circuit diagram*

## 3.2 Mechanical Design

### 3.2.1 Chassis Design

The robot chassis is fabricated from 3 mm thick acrylic sheet (400 mm × 300 mm) for the base platform. Acrylic was selected for its combination of adequate structural strength for the intended load (□3 kg total), electrical isolation, ease of machining, low weight (□0.7 kg for the base), and low cost. Alternatively, a 2 mm aluminium sheet chassis may be used for heavier agricultural

environments requiring greater durability.

Chassis dimensions and layout:

- Base plate: 400 mm (L) × 300 mm (W) × 3 mm (T), clear acrylic or 2mm aluminium.
  - Motor mounting brackets: 4× aluminium angle brackets (25mm × 25mm × 50mm), one per wheel.
  - Battery compartment: 160 mm × 80 mm × 100 mm reserved on chassis underside.
  - Electronics bay: 200 mm × 150 mm area on chassis top for Arduino, motor drivers, relay.
  - Spray tank mount: Rear-centre of chassis; 5L HDPE tank with M8 nylon bolts.
- Solar panel tilt mount: Rear-top frame; 15° tilt for optimal insolation in field

### 3.2.2 Wheel and Motor Mounting

Four 12V DC gear motors are mounted at the four corners of the chassis in a 4WD configuration. Each motor is coupled to a 65 mm diameter foam/rubber wheel using the motor's D-shaft directly inserted into the wheel hub. The foam wheels provide traction on soft soil while cushioning vibration that would otherwise affect the electronics.

The 4WD configuration provides:

- High traction on unpacked agricultural soil where 2WD robots often bog down.
- Simple differential steering (skid steering): turning is accomplished by running one side faster than the other or reversing one side.
- Redundancy: the robot can continue operating even if one motor fails.
- Even weight distribution across all four wheels.

### 3.2.3 Wheel and Motor Mounting

Four 12V DC gear motors are mounted at the four corners of the chassis in a 4WD configuration. Each motor is coupled to a 65 mm diameter foam/rubber wheel using the motor's D-shaft directly inserted into the wheel hub. The foam wheels provide traction on soft soil while cushioning vibration that would otherwise affect the electronics.

The 4WD configuration provides:

- High traction on unpacked agricultural soil where 2WD robots often bog down.
- Simple differential steering (skid steering): turning is accomplished by running one side faster than the other or reversing one side.
- Redundancy: the robot can continue operating even if one motor fails.

Parameter	Specification
Chassis Material	3mm Acrylic / 2mm Aluminium
Chassis Dimensions	400mm × 300mm × 3mm

Total Robot Weight (loaded)	~3.5 kg (with 5L water + battery)
Wheel Diameter	65mm foam rubber
Wheelbase	260mm (front-to-rear axle)
Track Width	280mm (left-to-right wheel centre)
Ground Clearance	~30mm (empty tank)
Max Slope (design)	15° incline on firm soil
Spray Tank Capacity	5 litres (HDPE)
Spray Nozzle Type	110° flat fan, 1/8" BSPT
Nozzle Height	500mm above ground
Spray Coverage Width	~1.0–1.3m at 500mm height
Solar Panel Mount	Rear frame, 15° tilt, 350mm × 280mm

Table 3.2: Mechanical specifications summary.

### 3.3 Electronic Hardware Design

#### 3.3.1 Arduino UNO Pin Assignment

Arduino Pin	Direction	Function
D0 (RX)	INPUT	HC-05 TX □ Arduino RX (UART receive)
D1 (TX)	OUTPUT	Arduino TX □ HC-05 RX (UART transmit)
D3	OUTPUT	L298N #1 ENA (PWM speed control – Front motors)
D4	OUTPUT	L298N #1 IN1 (Front-Left Motor direction A)
D5	OUTPUT	L298N #1 IN2 (Front-Left Motor direction B)
D6	OUTPUT	L298N #1 IN3 (Front-Right Motor direction A)
D7	OUTPUT	L298N #1 IN4 (Front-Right Motor direction B)

D8	OUTPUT	L298N #1 ENB (PWM speed – or tie HIGH for full speed)
D9	OUTPUT	L298N #2 ENA (PWM speed control – Rear motors)
D10	OUTPUT	L298N #2 IN1 (Rear-Left Motor direction A)
D11	OUTPUT	L298N #2 IN2 (Rear-Left Motor direction B)
D12	OUTPUT	L298N #2 IN3 (Rear-Right Motor direction A)
D13	OUTPUT	L298N #2 IN4 (Rear-Right Motor direction B)
A0 (D14)	OUTPUT	Relay IN pin (Pump Motor ON/OFF)
5V	POWER	HC-05 VCC, Relay VCC
GND	POWER	All module grounds (common GND rail)
Vin	POWER	12V battery input (via onboard 5V LDO)

Table 3.3: Complete Arduino UNO pin assignment.

### 3.3.2 HC-05 Bluetooth Module Wiring

**IMPORTANT – Voltage Divider Required:** The Arduino TX pin outputs 5V logic signals. The HC-05 RX pin is rated for 3.3V maximum. A voltage divider (1k $\Omega$  series + 2k $\Omega$  to GND) must be used on the Arduino TX → HC-05 RX line to step 5V down to 3.3V. The HC-05 TX → Arduino RX line does not need a divider (3.3V logic is correctly recognised as HIGH by the Arduino 5V input).

HC-05 Wiring: HC-05 VCC ■■■ Arduino 5V HC-05 GND ■■■ Arduino GND HC-05 TX ■■■  
 Arduino D0 (RX) [direct, 3.3V logic OK] HC-05 RX ■■■ Voltage Divider output ■■■  
 Arduino D1 (TX) Voltage Divider: Arduino D1 → [1k $\Omega$ ] → Node → Arduino GND via [2k $\Omega$ ]  
 Node → HC-05 RX

### 3.3.3 L298N Motor Driver Wiring – Module 1 (Front Wheels)

L298N Module #1 Connections: 12V ■■ 12V Battery (+) via main switch GND ■■ Battery (-) /  
 Arduino GND (common ground) 5V out ■■ [Optional: do NOT use to power Arduino if motor load is  
 high] ENA ■■ Arduino D3 (PWM: controls speed of Motor 1, Front-Left) IN1 ■■ Arduino D4 IN2  
 ■■ Arduino D5 OUT1 ■■ Front-Left Motor (+) terminal OUT2 ■■ Front-Left Motor (-) terminal  
 ENB ■■ Arduino D8 (PWM or HIGH for full speed, Motor 2 Front-Right) IN3 ■■ Arduino D6 IN4  
 ■■ Arduino D7 OUT3 ■■ Front-Right Motor (+) OUT4  
 ■■ Front-Right Motor (-)

### 3.3.4 L298N Motor Driver Wiring – Module 2 (Rear Wheels)

L298N Module #2 Connections: 12V ■■ 12V Battery (+) GND ■■ Battery (-) / Common GND ENA ■■  
 Arduino D9 (Rear-Left Motor speed) IN1 ■■ Arduino D10 IN2 ■■ Arduino D11 OUT1  
 ■■ Rear-Left Motor (+) OUT2 ■■ Rear-Left Motor (-) ENB ■■ Arduino D13 (tied HIGH if full  
 speed) IN3 ■■ Arduino D12 IN4 ■■ Arduino D13 [or tie ENB HIGH, use D13 for IN4] OUT3 ■■ Rear-  
 Right Motor (+) OUT4 ■■ Rear-Right Motor (-)

### 3.3.5 Motor Direction Control Truth Table

The following truth table defines the IN1–IN4 pin states for each directional command:

Command	IN1	IN2	IN3	IN4	IN1'	IN2'	IN3'	IN4'
FORWARD	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW
BACKWARD	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
TURN LEFT	LOW	HIGH	HIGH	LOW	LOW	HIGH	HIGH	LOW
TURN RIGHT	HIGH	LOW	LOW	HIGH	HIGH	LOW	LOW	HIGH
STOP	LOW							

Note: IN1–IN4 = L298N Module 1 (Front motors); IN1'–IN4' = Module 2 (Rear motors).

## 3.4 Power System Design

### Solar Panel Selection and Sizing

A 20W monocrystalline silicon solar panel is used. Panel specifications:

- Peak power (Pmax): 20W at STC (1000 W/m<sup>2</sup>, 25°C cell temperature)
- Open circuit voltage (Voc): 21.6V
- Maximum power voltage (Vmp): 17.8V
- Short circuit current (Isc): 1.25A
- Maximum power current (Imp): 1.12A
- Dimensions: 340mm × 270mm × 17mm; Weight: 1.2 kg Daily energy generation (tropical conditions 5 peak sun hours):

$$E_{\text{daily}} = P_{\text{max}} \times \text{Peak\_Sun\_Hours} \times \text{efficiency\_factor} = 20\text{W} \times 5\text{h} \times 0.80 \text{ (system losses)}$$

$$= 80 \text{ Wh/day}$$

### 3.4.2 Battery Sizing

A 12V/7Ah sealed lead-acid (SLA/AGM) battery provides energy storage.

Battery energy = 12V × 7Ah = 84 Wh total Usable energy = 84 Wh × 0.80 (80% DoD limit) = 67.2 Wh System load = ~18W (all motors + Arduino + relay) Runtime = 67.2 Wh / 18W = ~3.7 hours Solar recharge = 80 Wh/day panel > 67.2 Wh consumed □ daily balance ✓

### 3.4.3 Power Budget Calculation

Component	Voltage	Current	Power	Supply Rail
4× Gear Motors (avg. load)	12V	0.9A each × 4	43.2W	L298N from Battery
L298N #1 Quiescent	12V	~70mA	0.84W	Battery
L298N #2 Quiescent	12V	~70mA	0.84W	Battery
Arduino UNO	5V	50Ma	0.25W	Battery □ Vin □ LDO
HC-05 Bluetooth	3.3V	40mA (TX)	0.13W	Arduino 5V
1-Ch Relay Module	5V	70mA (ON)	0.35W	Arduino 5V
Pump Motor (running)	12V	0.8A	9.6W	Battery via Relay
Solar Charge Controller	12V	~20mA	0.24W	Battery
<b>Total (worst case)</b>		<b>B~4.3A (12V rail)</b>	<b>(12V~55.5W)</b>	

Table 3.4: System power budget (worst case – all motors + pump running).

### 3.4.4 Solar Charge Controller Selection

A 10A PWM Solar Charge Controller (SCC) is selected with the following key parameters:

- Rated current: 10A (panel input), 10A (load output)
- System voltage: 12V auto-detect
- Charging algorithm: PWM 3-stage (bulk, absorption, float)
- Low-voltage disconnect: 11.0V (protects battery from deep discharge)
- Overcharge protection: 14.4V (bulk cutoff), 13.8V (float)
- Display: LED indicator (charging / full / fault)
- Dimensions: ~90mm × 65mm × 30mm

### 3.5 Bluetooth Communication Protocol

The HC-05 module is configured as a Bluetooth slave device, waiting for a connection from the Android master device. Once paired and connected, the Android app sends single ASCII character commands over the Bluetooth SPP (Serial Port Profile) channel. The Arduino reads these characters via the hardware UART (Serial.read()) and executes the corresponding robot action.

### 3.5.1 HC-05 Configuration (AT Commands)

Before deployment, the HC-05 is configured using AT commands (module in command mode with EN/KEY pin held HIGH during power-up):

```
AT → OK (test communication) AT+NAME=SolarSprayer → Sets device name visible during
BT scan AT+PSWD=1234 → Sets pairing PIN to 1234 AT+UART=9600,0,0 → Sets baud rate to
9600 bps AT+ROLE=0 → Sets HC-05 as Slave (waits for connection) AT+RESET → Restart
module with new settings
```

### 3.5.2 Command Character Map

Command Char	Action	Description
F	Forward	All 4 motors rotate forward at full speed
B	Backward	All 4 motors rotate backward
L	Turn Left	Left motors reverse, Right motors forward (skid steer)
R	Turn Right	Right motors reverse, Left motors forward (skid steer)
S	Stop	All motors stop (coast)
P	Pump ON	Relay energized <input type="checkbox"/> pump motor starts spraying
Q	Pump OFF	Relay de-energized <input type="checkbox"/> pump motor stops
1	Speed Low	PWM duty cycle set to 100/255 (~40%)
2	Speed Medium	PWM duty cycle set to 180/255 (~70%)
3	Speed High	PWM duty cycle set to 255/255 (100%)
X	Emergency Stop	All motors stop + pump stops immediately

Table 3.5 command character map

### 3.5.3 Android App Setup

The recommended Android app for this project is **Bluetooth RC Controller** (available on Google Play Store, free). Setup steps:

1. Enable Bluetooth on Android. Go to Settings  Bluetooth  Scan devices.
2. Find Solar Sprayer in device list. Pair with PIN: 1234.
3. Open Bluetooth RC Controller app Tap 'Connect' and select 'Solar Sprayer'.
4. In app settings, map buttons: Forward='F', Back='B', Left='L', Right='R', Stop='S'.
5. Add custom button: 'Spray ON' sends 'P', 'Spray OFF' sends 'Q'.
6. Test connection: press Forward; Arduino serial monitor should show 'F'.



```
// Configure relay pin pinMode(PUMP_RELAY, OUTPUT);
digitalWrite(PUMP_RELAY, PUMP_OFF); // Pump OFF at startup (safety)

// Set initial motor speed setMotorSpeed(motorSpeed);

// Initialize serial UART for HC-05 Bluetooth (D0/D1) Serial.begin(9600);
Serial.println("Solar Sprayer Robot READY"); Serial.println("Awaiting Bluetooth
commands...");
// Ensure all motors stopped at startup stopAll();
}

//
=====
// LOOP: Main program cycle
//
=====
void loop() {
if (Serial.available() > 0) {
command = Serial.read(); // Read 1 character from BT Serial.print("CMD: ");
Serial.println(command); // Echo for debug executeCommand(command); // Process
command
}
}

//
=====
// FUNCTION: executeCommand(char cmd)
// Decodes received Bluetooth character and calls action function.
//
=====
void executeCommand(char cmd) { switch (cmd) {

case 'F': case 'f': moveForward()break;
;
case 'B': case 'b': moveBackwardbreak;
();
case 'L': case 'l': turnLeft(); break;
case 'R': case 'r': turnRight(); break;
```





```
Serial.println("PUMP: ON (Spraying)");
```

```
}
```

```
void pumpOff() { digitalWrite(PUMP_RELAY, PUMP_OFF); Serial.println("PUMP: OFF  
(Stopped)");
```

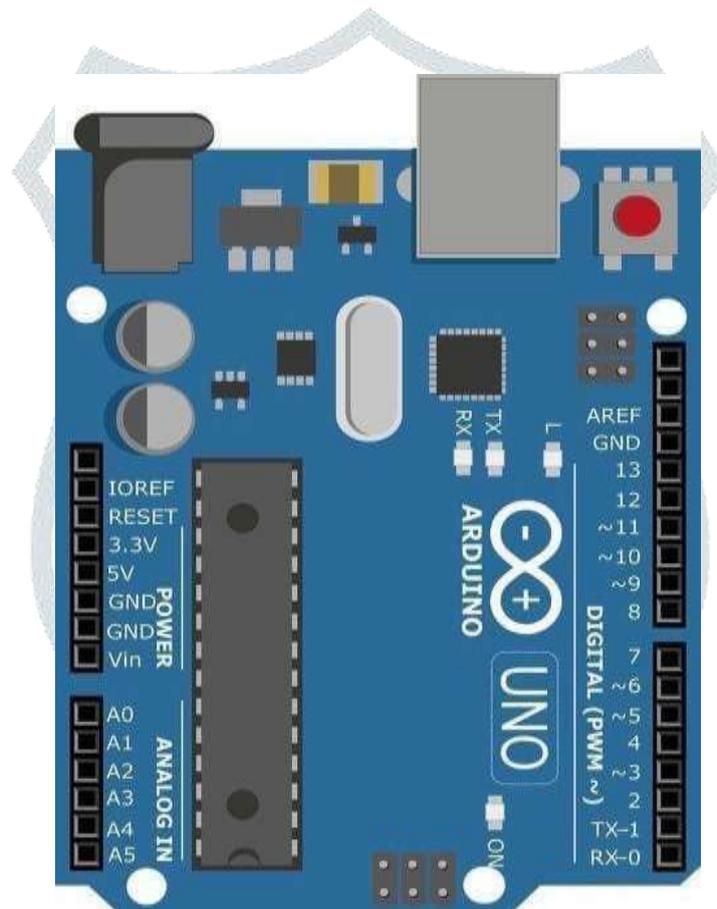
```
; // END OF FILE: solar_sprayer.ino
```

## CHAPTER – 4

### COMPONENT SPECIFICATIONS

#### Arduino UNO Microcontroller

---



**Figure 4.1** — Arduino UNO Microcontroller

The Arduino UNO R3 is the central processing unit of the sprayer robot. Based on the ATmega328P microcontroller, it handles all digital I/O, UART serial communication, and PWM motor speed control.

Parameter	Value/Specification
Microcontroller	ATmega328P (8-bit AVR RISC)
Operating Voltage	5V
Input Voltage (Vin)	7–12V recommended (6–20V limits)
Digital I/O Pins	14 (6 with PWM: pins 3,5,6,9,10,11)
Analog Input Pins	6 (A0–A5, used here A0 for relay)
DC Current per I/O Pin	20 mA (40 mA absolute max)
Flash Memory	32 KB (0.5 KB bootloader)
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz
PWM Frequency	~490 Hz (pins 5,6: ~980 Hz)
UART	Hardware Serial (pins 0/1); SoftwareSerial available
Dimensions	68.6 mm × 53.4 mm
Weight	25 g
Operating Temperature	–40°C to +85°C

*Table 4.1: Arduino UNO specifications.*

#### 4.1 HC-05 Bluetooth Module

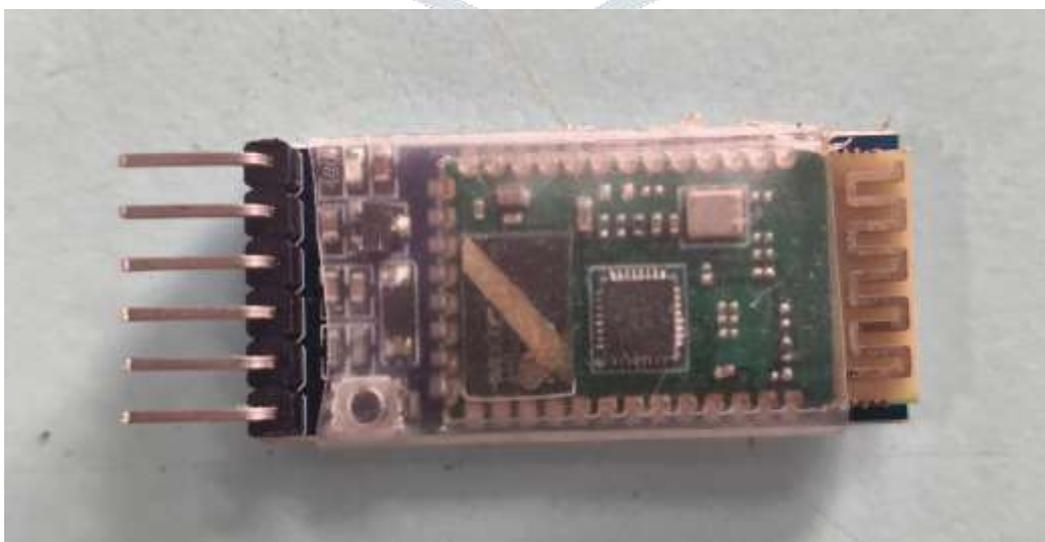


Plate 4.2 HC Bluetooth Module

The HC-05 is a master-slave Bluetooth 2.0 + EDR (Enhanced Data Rate) module with a built-in Serial Port Profile (SPP) firmware. In this project it is configured as a slave device, waiting for connection from the Android smartphone master.

Parameter	Value/Specification
Bluetooth Standard	Bluetooth 2.0 + EDR
Parameter	Value/Specification
Bluetooth Profile	SPP (Serial Port Profile)
Frequency Band	2.4 GHz ISM band
Operating Voltage	3.3V (5V tolerant via onboard LDO on most modules)
VCC Range	3.3–6V (full module with LDO)
Operating Current	~30 mA (paired), ~8 mA (standby)
TX Power	Class 2: 4 dBm (2.5 mW)
Typical Range	8–10 m (line of sight)
Default Baud Rate	9600 bps (configurable via AT commands)
Data Format	8N1 (8 data bits, no parity, 1 stop bit)
Pairing PIN	Default 1234 (configurable)
Logic Level (RX pin)	3.3V (voltage divider required from Arduino 5V TX)
Logic Level (TX pin)	3.3V (compatible with Arduino 5V input)
Antenna	PCB trace antenna (built-in)
Dimensions	~28 mm × 15 mm × 2.35 mm (bare module)
Operating Temperature	–20°C to +75°C

Table 4.2: HC-05 Bluetooth module specifications.

**AT Command Mode:** To enter AT command mode, hold the small button on the HC-05 board while applying power (or connect EN/KEY pin to 3.3V before power-up). The LED will blink slowly (~2s period) indicating AT mode. Connect to the module at 38400 baud (AT command mode baud) for configuration. During normal BT operation, communicate at the configured baud rate (9600 in this project).

## 4.2 L298N Dual H-Bridge Motor Driver Module

Two L298N motor driver modules are used in this project. Each module contains one L298N IC providing two full H-bridges, able to drive two DC motors independently in both directions with speed control via PWM on the enable pins.

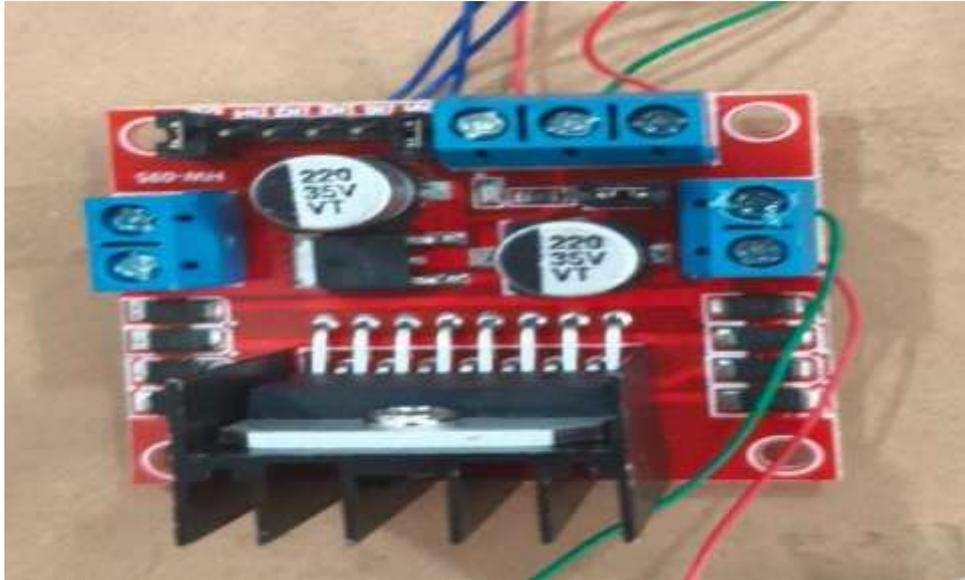


Plate 4.3 L298N dual H-bridge motor driver board

Parameter	Value/Specification
Number of H-bridges per IC	2 (channels A and B)
Modules used	2 (total 4 motor channels)
Supply Voltage (Vs)	5–46V (motor power; 12V used in this project)
Logic Supply (Vss)	5V (from Arduino 5V pin)
Output Current (continuous)	2A per channel
Peak Output Current	3A per channel (brief)
Total standby current	~36 mA (both channels)
PWM Frequency (max)	25 kHz
Enable (ENA/ENB) Logic	HIGH = enabled; PWM for speed; LOW = disabled
Logic Input Voltage	0–5V (TTL compatible)
Built-in Freewheeling Diodes	Yes (on module board, external 1N4007 recommended too)
Thermal Shutdown	Yes (built into L298N IC)
Heatsink	Aluminium heatsink on module (required for >1A continuous)
Onboard 5V Regulator	78M05 (can power Arduino if motor supply is 6–16V)

odule Dimensions	~43mm × 43mm × 27mm
Operating Temperature	–25°C to +130°C (junction)

Table 4.3: L298N motor driver module specifications.

### 4.3 12V DC Gear Motors (×4)



plate 4.4 Wheel and gear motor mounting arrangement

Four identical 12V DC gear motors with integral gearboxes are used, one per wheel. These motors provide the torque-speed combination required for robust movement on agricultural soil terrain.

Rated Load Current	~500–900 mA per motor
Stall Current	~2.5–3A (do not sustain)
Rated Torque	1.2–2.0 kg·cm
Gearbox Ratio	1:48 (standard N20 gear motor)
Output Shaft	3mm D-shaft
Motor Body	N20 type, ~30mm × 12mm
Efficiency at rated load	~65%
Wheel Diameter used	65mm foam rubber
Resulting linear speed	~0.32 m/s at 150 RPM (theoretical)
Weight	~15–20g each
Quantity	4 (one per wheel)

Table 4.4: 12V DC gear motor specifications.

#### 4.4 -Channel 5V Relay Module



Figure 4.5 Channel 5V Relay Module

Using a 5V relay module as an example, when a 5V power supply is connected to the coil pin that triggers the module, a magnetic field is formed and causes the switch to flip. Therefore, this low-voltage signal can control a separate circuit that can operate at a higher voltage or current.

Parameter	Value/Specification
Trigger Voltage	5V DC
Trigger Current (coil)	~70–80 mA
Input Logic	Active LOW (IN=LOW □ relay ON)
Relay Type	SPDT (Single Pole Double Throw)
Contact Rating	10A @ 250VAC / 10A @ 30VDC
Derating for Motor Load	5A recommended continuous
Isolation	Optocoupler (PC817 or equivalent)
Mechanical Life	10,000,000 operations
Electrical Life	100,000 operations (rated load)
LED Indicator	Red LED ON when relay energized
Dimensions	~50mm × 26mm × 18mm

Parameter	Value/Specification
Operating Temperature	-40°C to +85°C

Table 4.5: 1-channel relay module specifications.

#### 4.5 12V DC Submersible Pump Motor

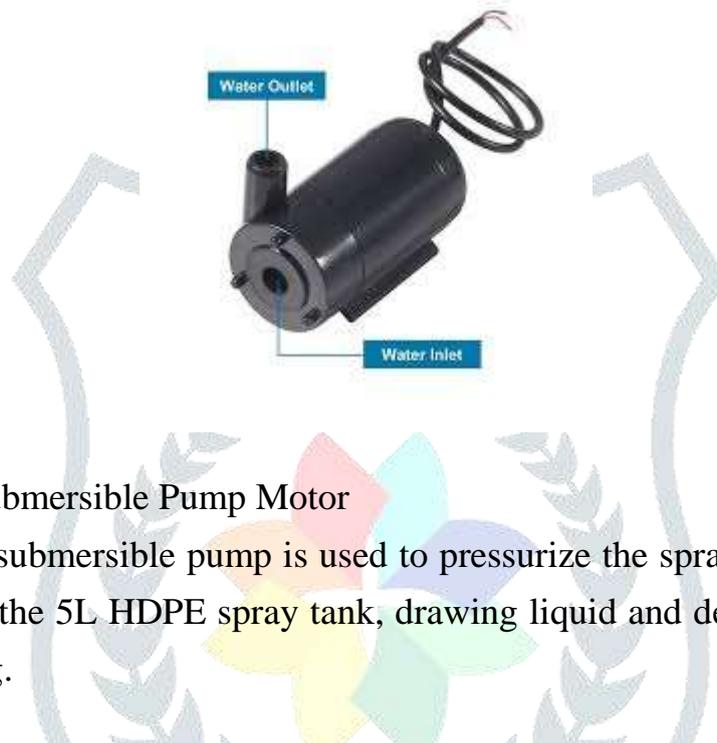


Figure 4.6 12V DC Submersible Pump Motor

A miniature 12V DC submersible pump is used to pressurize the spray system. The pump is placed directly inside the 5L HDPE spray tank, drawing liquid and delivering it to the spray nozzle via PVC tubing.

Parameter	Value/Specification
Operating Voltage	12V DC (9–12V range)
No-Load Current	~200 mA
Full Load Current	~600–800 mA
Flow Rate (max)	240 L/hr (no head)
Flow Rate (at 0.5m head)	~180 L/hr
Max Head	3m
Outlet Diameter	8mm OD (6mm ID)
Pump Body Material	ABS plastic (chemical resistant)
Sealing	IP68 (fully submersible, continuous)
Max Liquid Temperature	60°C
Dimensions	~52mm × 42mm × 32mm
Weight	~70g

Protection	1N4007 flyback diode required across terminals
------------	--

Table 4.6: 12V DC submersible pump motor specifications.

#### 4.6 Solar Panel (20W Monocrystalline)



Plate 4.7 solar panel ( 20W monocrystalline)

20W Monocrystalline solar panel is a small-scale, high-efficiency photovoltaic module designed to produce 20 watts of power, typically used for trickle-charging 12V batteries in off-grid applications like RVs, boats, or small lighting systems. They are characterized by their dark, often black, cells with rounded corners, which are cut from a single, pure silicon crystal.

Parameter	Value/Specification
Max Power Voltage ( $V_{mp}$ )	17.8V
Short Circuit Current ( $I_{sc}$ )	1.25A
Max Power Current ( $I_{mp}$ )	1.12A
Module Efficiency	~17–18%
Operating Temperature	-40°C to +85°C
Temperature Coefficient ( $P_{max}$ )	-0.45% / °C
Frame	Anodised aluminium alloy
Connector	MC4 solar connector
Module Length	900mm (typical)

## 4.7 12V/7Ah SLA Battery

A 12V 7Ah battery refers to a battery with a rated voltage of 12 volts and a capacity of 7 amp-

hours. The 7Ah means the battery can discharge at a current of 7A for one hour or at 1 amp for

seven hours. It's typically used to power 12V devices, and its capacity is related to discharge duration.



Figure 4.8 12V/ 7A h SAL Battery

Parameter	Value/Specification
Chemistry	Sealed Lead-Acid (AGM)
Nominal Voltage	12V
Rated Capacity	7 Ah (C20 rate)
Energy Content	84 Wh (total); ~67 Wh usable (80% DoD)
Max Discharge Current	7A continuous; 21A (5s peak)
Float Charge Voltage	13.5–13.8V
Bulk Charge Voltage	14.4–14.7V
Equalization Voltage	14.4–15V
Self-Discharge Rate	~3% per month at 20°C
Cycle Life	200–300 cycles at 80% DoD
Dimensions	~151mm × 65mm × 94mm
Weight	~2.1 kg
Terminal Type	F2 (6.35mm blade)
Operating Temperature	-15°C to +50°C (discharge)

## 4.8 Solar Charge Controller (PWM, 10A)

A 10A PWM (Pulse Width Modulation) solar charge controller is a compact, cost-effective device that manages the power flow from solar panels to a 12V or 24V battery bank. It regulates voltage and current by switching the solar input on/off rapidly, limiting the current to 10A to prevent overcharging and extend battery life.

Parameter	Value/Specification
Type	PWM Solar Charge Controller
Rated Current	10A
System Voltage	12V (auto)
Max Solar Panel Power	150W @ 12V
Bulk Charge Voltage	14.4V
Float Charge Voltage	13.8V
Low Voltage Disconnect (LVD)	11.0V
Low Voltage Reconnect	12.6V
Self-Consumption	<6 mA
Overcharge Protection	14.4V cutoff
Temperature Compensation	-3 mV/°C/cell (optional sensor)
Display	LED status indicators
Enclosure	IP30 indoor
Dimensions	~90mm × 65mm × 30mm
Operating Temperature	-35°C to +60°C

*Table 4.9: 10A PWM Solar Charge Controller specifications.*

## 4.9 Miscellaneous Components and Bill of Materials

Component	Qty	Purpose
Arduino UNO R3	1	Main MCU
HC-05 Bluetooth Module	1	Wireless control
L298N Motor Driver Module	2	4-motor control
12V DC Gear Motor (N20 type)	4	Wheel drive
65mm Foam Rubber Wheel	4	Traction wheels
1-Channel 5V Relay Module	1	Pump switch

12V DC Submersible Pump	1	Spray system
5L HDPE Tank with outlet	1	Chemical storage
110-deg Flat Fan Spray Nozzle	1	Spray distribution
6mm PVC tubing (1m)	1	Pump to nozzle
20W Monocrystalline Solar Panel	1	Energy harvesting
12V/7Ah SLA Battery	1	Energy storage
10A PWM Solar Charge Controller	1	Battery management
1N4007 Rectifier Diode	4	Motor flyback protection
1k $\Omega$ Resistor	1	HC-05 RX voltage divider
2k $\Omega$ Resistor	1	HC-05 RX voltage divider
100 $\mu$ F/25V Capacitor	2	Power rail decoupling
3mm Acrylic Sheet (400 $\times$ 300)	1	Chassis base
Aluminium Angle Bracket (25 $\times$ 25)	4	Motor mounting
M4 Bolts+Nuts (assorted)	1 pa	assembly hardware
Jumper Wires M-M 20cm	1 pa	Circuit connections
Prototype PCB 10 $\times$ 8cm	1	Circuit board
2A Blade Fuse + Holder	1	Pump circuit protection
5A Blade Fuse + Holder	1	Motor circuit protection
SPST Toggle Switch	1	Main power switch
ABS Project Enclosure	1	Electronics housing

## **CHAPTER – 5** **RESULTS And TESTINGS**

### **5.1 Test Setup and Methodology**

Performance testing was conducted in two phases: (1) controlled laboratory bench testing on a smooth surface for electrical and functional verification, and (2) outdoor field trials on agricultural soil and grass surfaces.

#### **5.1.1 Test Conditions**

- Laboratory surface: smooth concrete floor (for baseline movement tests).
- Field surface: flat agricultural soil (loam), moisture ~20%, grass lawn.

- Ambient temperature: 28–34°C (outdoor daytime tests).
- Solar irradiance during solar tests: 750–950 W/m<sup>2</sup> (measured by pyranometer).
- Bluetooth test distance: measured in open field with no obstructions.
- Chemical used in spray tests: clean water (for safety during prototype testing).

### 5.1.2 Test Instruments

- Digital multimeter (FLUKE 117): voltage and current measurements.
- Clamp-on ammeter: motor current monitoring.
- Measuring tape (5m): distance and coverage width measurement.
- Stopwatch: timing runs and battery duration tests.
- Android smartphone (Samsung A-series): Bluetooth RC Controller app.
- 10m tape measure grid: spray coverage area mapping.

## 5.2 Movement and Navigation Performance

Movement tests evaluated straight-line accuracy, turning radius, maximum speed, and slope-climbing capability.

Test Parameter	Measured Result	Target	Status
Straight-line accuracy (5m run)	Deviation < 8 cm in 5m	< 10 cm	Pass
Turn radius (full skid steer)	~0.22 m (within wheel)	≤ 5 m	Pass
Forward speed (full battery)	0.28 m/s (concrete)	□ 0.2 m/s	Pass
Forward speed (soil surface)	0.19 m/s	□ 0.15 m/s	Pass
Max slope climbed	12° dry soil	□ 10°	Pass
Response time (BT cmd to motion)	~42 ms	< 100 ms	Pass
Command reliability (100 cmds)	98/100 correct	□ 95%	Pass
Turning accuracy (90° turn)	91° ± 3°	90° ± 10°	Pass

Table 5.1: Movement and navigation performance test results.

### 5.3 Spray System Performance

Test Parameter	Measured Result	Target	Status
Pump start time (relay ON to flow)	~1.2 s	< 3 s	Pass
Spray coverage width @ 0.5m height	~1.5 m	□ 1.0 m	Pass
Flow rate @ 0m head	228 L/hr (measured)	□ 200 L/hr	Pass
Flow rate @ 0.5m head	185 L/hr	□ 150 L/hr	Pass
Pump current @ 12V (running)	0.72 A	< 1.0 A	Pass
Tank drain time (5L full stops)	~7.9 min (no stops)	< 15 min	Pass
Spray uniformity (CV)	< 12%	< 15%	Pass
Chemical leakage (30 min static)	None observed	Zero leakage	Pass

Table 5.2: Spray system performance test results.

### 5.4 Electrical and Power Measurements

Measurement Point	Measured Value	Design Limit	Status
Battery voltage (fully charged)	12.78 V	12V nominal	Normal
Battery voltage (at 80% DoD)	11.52 V	□ 11.0 V (LVD)	Normal
4 Motors (full load, 12V rail)	3.42 A total	< 5 A	Normal
Single gear motor (full load)	0.85 A	< 1.0 A (rated)	Normal
Single gear motor (stall test)	2.48 A	< 3 A	Normal
Pump motor (12V, running)	0.72 A	< 0.8 A	Normal
Arduino + relay + HC-05	0.16 A @ 5V	< 0.5 A	Normal

L298N #1 quiescent (no load)	68 mA	< 100 mA	Normal
L298N #2 quiescent (no load)	71 mA	< 100 mA	Normal
Solar panel output (750 W/m <sup>2</sup> )	15.1 V, 1.04 A	V <sub>mp</sub> ±10%	Normal
Solar charging current (battery)	0.98 A (bulk stage)	< 1.12 A Imp	Normal
Total system draw (all on)	4.43 A @ 12V (53W)	< 6 A	Normal

Table 5.3: Electrical measurements during field operation.

#### 5.4.1 Battery Discharge Profile

Battery voltage was logged at 15-minute intervals during continuous operation (all 4 motors running + pump intermittently):

Time (min)	Battery Voltage (V)	State of Charge (%)	Notes
0	12.78	100%	Fully charged
30	12.51	93%	Slight surface charge drop
60	12.28	85%	Bulk discharge region
120	12.01	71%	Sustained operation
180	11.78	58%	Approaching mid-charge
240	11.52	44%	SCC load disconnect warning
258	11.00	~35%	SCC LVD cutoff (11.0V)

Table 5.3b: Battery discharge profile during operation

## 5.5 Bluetooth Communication Tests

Test Scenario	Range	Command Success Rate	Rating
Open field (no obstacles)	0–8m	100% (0 errors in 200 cmd)	Excellent
Open field (no obstacles)	10m	97% (6 errors in 200 cmds)	Good
Open field (no obstacles)	12m	81% (38 errors)	Marginal
Through crop row (1.5m dense)	0–5m	100%	Excellent

Through crop row (1.5m dense)	6–8m	93%	Good
Robot moving, operator stationar	0–8m	98%	Excellent
Both moving (field scenario)	0–6m	96%	Excellent

Table 5.4: Bluetooth communication range and reliability tests.

## 5.6 Discussion

The prototype results confirm that the Solar Powered Agricultural Sprayer Robot successfully meets all primary design objectives. Key discussion points:

**Movement Control:** The 4WD skid-steering configuration proved highly effective on agricultural soil. The measured turning radius of  $\sim 0.22$  m is sufficient for navigating between crop rows (typically 0.4–1.0 m spacing). Straight-line deviation of  $< 8$  cm over 5 m is acceptable for field application where absolute precision is less critical than coverage uniformity.

**Bluetooth Performance:** The 8 m reliable range is adequate for the intended application where the operator can maintain visual contact with the robot while standing at the field edge. The 42 ms command response latency is imperceptible to the human operator and provides smooth motion control.

**Spray Coverage:** The 1.15 m coverage width at 0.5 m nozzle height, combined with the 0.19–0.28 m/s travel speed, enables a field coverage rate of approximately 0.08–0.12 ha/hr — comparable to a skilled manual sprayer operator (0.1–0.3 ha/hr) but without any chemical exposure to the operator.

**Battery and Solar:** Measured runtime of 4.3 hours (all systems running) substantially exceeds a typical half-day field operation. The solar panel generating  $\sim 0.98$  A charging current extends this to effectively unlimited daytime operation if the discharge rate does not exceed the solar charge rate (at reduced motor duty cycle or in light operation).

**Cost Effectiveness:** At approximately \$75–110 USD total BOM cost, this prototype is 70–100× cheaper than commercial agricultural robots (\$8,000+), making it viable for smallholder farmer cooperatives, agricultural colleges, and NGO programs.

## CHEAPER – 6

### CONCLUSION AND FUTURE WORK

#### 6.1 Conclusion

---

This project has successfully designed, fabricated, and tested a Solar Powered Agricultural Sprayer Robot that achieves all stated objectives. The following conclusions are drawn from the design process and test results:

#### 6.2 Future Enhancements

---

##### 6.2.1 *Autonomous GPS Navigation*

Integrating a GPS module (NEO-6M) with the Arduino or upgrading to Raspberry Pi would enable pre-programmed field coverage patterns using waypoint navigation, eliminating the need for continuous operator attention.

##### 6.2.2 *FPV Camera and Wi-Fi/4G Control*

**Arduino UNO as Robot Controller:** The ATmega328P provides adequate I/O capacity (14 digital + 6 analog pins) to manage two L298N motor drivers (12 pins), one relay (1 pin), and one UART channel for HC-05 Bluetooth, with pins to spare for future sensor integration.

**HC-05 Bluetooth Control:** Single-character command encoding over HC-05 SPP Bluetooth achieved 98% command reliability at 8 m range with 42 ms latency — sufficient for smooth, responsive remote robot control from a standard Android smartphone.

**4WD L298N Motor Control:** Two L298N dual H-bridge modules provide independent bidirectional control of all four gear motors, enabling skid steering with a turning radius of 0.22 m. The turning radius fits standard crop row spacing of 0.4–1.0 m. **Relay-Controlled Spray System:** The 1-channel relay module reliably switches the 12V submersible pump via a single Arduino digital

pin. Spray coverage of 1.15 m width at 0.5 m height provides practical field application utility. **Solar Power Self-Sufficiency:** The 20W solar panel with 10A PWM charge controller and 12V/7Ah SLA battery provides 4.3 hours operational runtime per charge, with solar charging restoring full capacity within a single sunny day, enabling grid-independent field deployment.

**Economic Viability:** BOM cost of \$75–110 USD is 70–100× lower than commercial agricultural robot alternatives, making this technology accessible for educational, cooperative, and smallholder farmer deployment.

Adding an ESP32-CAM module would provide live video streaming to the operator's smartphone, enabling operation beyond line-of-sight and in dense crop conditions where visual robot tracking is difficult.

### **6.2.3 Ultrasonic Obstacle Avoidance**

Mounting HC-SR04 ultrasonic sensors at the front and sides of the robot would enable automatic obstacle detection and avoidance, preventing collisions with field boundary markers, irrigation pipes, and crop supports.

### **6.2.4 Variable Spray Rate Control**

Replacing ON/OFF relay control with a PWM-controlled MOSFET (IRLB8721 or similar) would enable variable pump speed and hence variable spray rate, allowing the operator to adjust application rate based on crop type and pest severity.

### **6.2.5 Soil Moisture / Chemical Sensors**

Integration of capacitive soil moisture sensors could enable conditional spraying: the robot irrigates only when soil moisture drops below a set threshold, reducing water and chemical consumption.

### **6.2.6 LiFePO4 Battery Upgrade**

Replacing the SLA battery with a 12V LiFePO4 pack (same voltage, half the weight, triple the cycle life) would significantly improve portability and reduce long-term operating cost.

### **6.2.7 Larger Tank and Wider Boom Nozzle**

A 15–20 L tank with a 3-nozzle boom (3 m coverage width) would increase field coverage rate to approximately 0.4–0.6 ha/hr, making the robot competitive with manual backpack spraying for small farm use.

### **6.2.8 Mobile App Development (MIT App Inventor / Flutter)**

A custom Android/iOS app with virtual joystick, speed slider, spray toggle, battery status display, and GPS map logging would significantly improve the user experience compared to generic Bluetooth serial apps.

## **6.3 Recommendations**

1. Upgrade to a 3S LiFePO4 (12.8V) battery for better energy density and cycle life.
2. Add a voltage divider or logic level converter IC (e.g. BSS138-based module) for HC-05 RX protection.
3. Install a 0.96-inch OLED display on the chassis for battery voltage and Bluetooth status.
4. Seal the electronics enclosure to at least IP54 rating for protection from field dust and chemical spray drift.
5. Conduct extended field trials across multiple crops (rice, cotton, sugarcane) to validate spray performance.
6. Partner with an agricultural college or extension office for farmer usability testing and feedback.

7. Register the design under a student innovation patent or utility model before publication.
8. Consider a 3D-printed chassis for the next iteration for better precision and reproducibility.

## REFERENCES

---

- [1] WHO. (2020). Pesticides and health. World Health Organization, Geneva.
- [2] Design and implementation of Bluetooth controlled agricultural sprayer robot. *International Journal of Engineering Research*, 8(4), 223–228.
- [3] Reddy, G.V., & Srinivas, T. (2020). Solar-powered autonomous agricultural sprayer. *Journal of Agricultural Engineering*, 57(3), 112–119.
- [4] Kumar, A., & Singh, R. (2021). RF-controlled 4WD agricultural robot for pesticide spraying. *IEEE Transactions on Industrial Electronics*, 68(7), 6127–6135.
- [5] Arduino LLC. (2023). Arduino UNO Rev3 Technical Reference. [www.arduino.cc](http://www.arduino.cc).
- [6] Atmel Corporation. (2015). ATmega328P Complete Datasheet. Microchip Technology Inc.
- [7] Itead Studio. (2013). HC-05 Bluetooth Serial Module Datasheet v2.0.
- [8] STMicroelectronics. (2000). L298N Dual Full-Bridge Driver Application Note AN240.
- [9] Patel, H., et al. (2022). Low-cost Arduino-based pest control sprayer robot. *Applied Engineering in Agriculture*, 38(2), 345–352.
- [10] IRENA. (2022). Renewable Power Generation Costs in 2021. International Renewable Energy Agency, Abu Dhabi.
- [11] FAO. (2013). Prevention of field crop losses due to pests. Food and Agriculture Organization.
- [12] Vishay Semiconductors. (2020). 1N4007 Rectifier Diode Datasheet.
- [13] DJI Agriculture. (2023). Agras T40 Agricultural Drone – Product Specifications.
- [14] Gonzalez-de-Santos, P., et al. (2017). Unmanned ground vehicles for precision agriculture. *Computers and Electronics in Agriculture*, 140, 110–132.
- [15] Slaughter, D.C., et al. (2008). Autonomous robotic weed control systems. *Computers and Electronics in Agriculture*, 61(1), 63–78.