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Smart Solar-Powered Web-Controlled System for Automated Agricultural Operations

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Abstract

Agriculture is an essential sector that supports both human life and economic development. However, conventional farming methods require significant manual effort and consume considerable time. To overcome these limitations, this work proposes a solar-powered, mobile-controlled multifunctional agricultural robot based on an Arduino platform.The system is capable of performing various farming activities such as soil preparation, seed sowing, irrigation, and weed cutting. It is operated using a Bluetooth-enabled mobile application, allowing users to control the robot remotely. The use of solar energy ensures uninterrupted operation even in areas without a reliable electricity supply.The integration of sensors, actuators, and control units enables efficient and precise task execution. This system minimizes human effort, reduces operational cost, and promotes sustainable farming practices. The proposed model represents a step toward modern smart agriculture using renewable energy and automation technologies.

Keywords: *HC-05 Bluetooth Module; Arduino UNO; Regulated Power Supply.*

1. Introduction

Agriculture plays a significant role in supporting livelihoods and ensuring food security, especially in developing countries. Despite its importance, many agricultural processes still rely on manual labor, making them time-consuming and less efficient. Tasks such as sowing, irrigation, and weed removal often require continuous human involvement, leading to increased labor costs and reduced productivity.Recent advancements in automation and robotics have opened new possibilities for improving agricultural efficiency. Automated systems can perform repetitive operations with better accuracy and consistency.In this project, a solar-powered agricultural robot controlled via a mobile application is developed using an Arduino microcontroller. The robot is designed to perform multiple operations including soil digging, seed sowing, watering, and grass cutting. The use of solar energy allows the system to function in remote locations without dependency on grid power.This approach not only reduces manual workload but also improves efficiency and resource utilization. Additionally, it provides a foundation for future enhancements such as IoT integration and autonomous navigation.

1.1.Proposed Solution

The proposed system consists of a solar-powered robotic platform that can be controlled wirelessly through a mobile application. Communication between the user and the robot is established using a Bluetooth module.

The robot includes several functional units:
- A seed sowing mechanism for controlled seed placement
- A watering system using a pump and relay
- A grass cutting unit driven by a motor
- A movement system using DC motors for navigation

All operations are coordinated by the Arduino controller, which processes user commands and controls the respective modules efficiently.

Block Diagram

This Agribot is a solar-powered, Bluetooth-controlled multipurpose farming robot. Electrical energy generated from the solar panel is stored in a 12V battery through a charge controller and regulated using a 7805 voltage regulator. The system is controlled using an Arduino UNO, along with Bluetooth module and L298N motor driver to automate robot movement and farming operations.which is suitable for powering sensitive electronic components like the microcontroller and communication modules. At the core of the system is the Arduino UNO (ATmega328P), which acts as the brain of the robot. It processes input signals and controls all output devices. The Arduino receives inputs from modules such as the ESP32 camera, which can be used for live monitoring or image processing, and the HC-05 Bluetooth module, which enables wireless control of the robot through a smartphone or other devices.

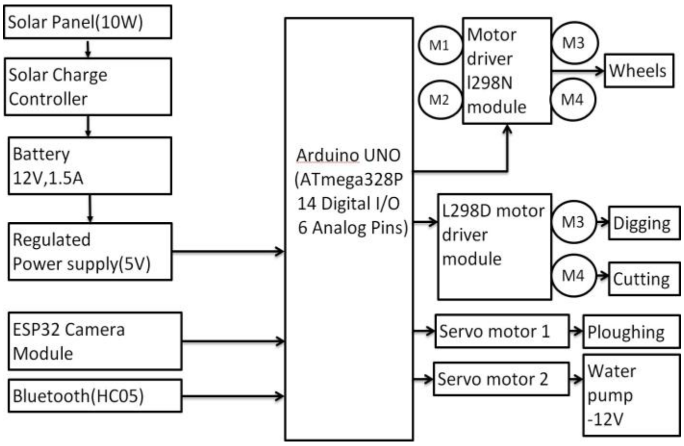

Figure 1 Arduino UNO

1.2.Components Specifications

Table 1 Hardware Requirement

S.I No	Component	Specification	Application
1	Arduino Uno	ATmega328P, 5V, 14 Digital I/O, 6 PWM, 6 Analog	Main controller for system operations
2	L298N Motor Driver	Dual H-Bridge, 5–35V, 2A/channel	Controls speed and direction of DC motors
3	HC-05 Bluetooth Module	2.4 GHz, UART, 3.3–6V, ~10m range	Wireless communication with mobile
4	DC Motor	6–12V, Bidirectional, variable RPM	Drives robot wheels
5	Servo Motor	4.8–6V, 0°–180°, PWM control	Controls seed dispensing mechanism
6	Water Pump	12V DC, Submersible	Irrigation/watering system
7	Solar Panel	12V, 3W–10W	Renewable power
8	Solar Charge Controller	12V, PWM/MPPT	Regulates battery charging
9	Rechargeable Battery	12V, 1.3Ah	Energy storage
10	Relay Module	5V, Electromechanical switch	Controls high-power loads (pump)
11	Regulated Power Supply	Stable DC output	Supplies regulated voltage
12	ESP32-CAM Module	Wi-Fi + Bluetooth, Camera	Image capture
13	DC Crop Cutter	775 Motor with HSS blade	Grass/crop cutting mechanism

1.3.Working

The system operates with energy that a solar panel generates from converting sunlight into electrical energy. The system uses a charge controller to handle energy storage in a rechargeable battery which allows the robot to operate during periods without sunlight. The system uses an Arduino Uno as its main control device, which functions as the systems central processing unit. The system receives user commands through a mobile application, which uses an HC-05 Bluetooth module to send signals that control various robot functions. The robot uses DC motors to achieve movement, which enables the robot to travel forward and backward while turning in multiple directions. The robot agricultural system operates through built-in mechanisms, which include a seed sowing unit that plants seeds at fixed intervals to achieve correct seed spacing and an irrigation system which uses a pump to supply controlled water to the soil for efficient irrigation. A motor-driven cutting blade removes unwanted grass or weeds from the field. The system deploys a regulated power supply to deliver a stable voltage to all electronic components which protects equipment from damage and increases system reliability while using a relay module to control high-power devices such as the water pump. Users can monitor field conditions through an ESP32-CAM module which captures images and video and transmits them wirelessly to the user. System operations begin through user commands which enables the system to use energy efficiently while preventing system overload. The system uses solar energy together with basic automation and control techniques to execute agricultural tasks which enhance farming operations by making them more efficient and decreasing their need for human labor. The system requires additional improvement through the installation of soil moisture and temperature sensor systems which will provide the capability to operate in semi-automatic mode. Figure 1 Step-1 Playstore APP, Figure 2 Step-2 Controlling commands, Figure 3 Step-3 Real Time Control, Figure 4 Hardware Kit

1.4.Software Requirement

1.4.1. Code Implementation

```
#include <Servo.h>

String voice = "";

// -------- Motor Pins -------- int
motor1A = 2;
int motor1B = 3;
int motor2A = 4;
int motor2B = 5;

// -------- Cutter (Relay - Active LOW) -------- int
cutter = 7;

// -------- Servo --------
Servo ploughServo;
int servoPin = 9;
//------------------MovementFunctions---------------------------//
void forward() {
 digitalWrite(motor1A, HIGH);
 digitalWrite(motor1B, LOW);
 digitalWrite(motor2A, HIGH);
 digitalWrite(motor2B, LOW);


void backward() { digitalWrite(motor1A, LOW);
  digitalWrite(motor1B, HIGH); digitalWrite(motor2A, LOW);
  digitalWrite(motor2B, HIGH);

  digitalWrite(cutter, LOW);   //
Cutter OFF (Active LOW)
ploughServo.write(90);

// Neutral position
}
}


void left() { digitalWrite(motor1A,
  LOW); digitalWrite(motor1B,
  HIGH); digitalWrite(motor2A,
  HIGH); digitalWrite(motor2B,
  LOW);
}

void right() { digitalWrite(motor1A,
  HIGH); digitalWrite(motor1B,
  LOW); digitalWrite(motor2A,
  LOW); digitalWrite(motor2B,
  HIGH);
}

void stopRobot() {
  digitalWrite(motor1A, LOW);
  digitalWrite(motor1B, LOW);
  digitalWrite(motor2A, LOW);
  digitalWrite(motor2B, LOW);
}

//---------------------------------------------------------//


void setup() { Serial.begin(9600);

  pinMode(motor1A,         OUTPUT);
  pinMode(motor1B,         OUTPUT);
  pinMode(motor2A,         OUTPUT);
  pinMode(motor2B, OUTPUT);

  pinMode(cutter, OUTPUT); ploughServo.attach(servoPin);

  // -------- Initial Safe States -------- stopRobot();
//---------------------------------------------------------//

void loop() {
```

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```
  while (Serial.available()) {
    delay(10);
    char c = Serial.read(); if
    (c == '#') break; voice
    += c;
  }

  if (voice.length() > 0) {

    voice.toLowerCase();

    // -------- Movement --------
    if (voice == "forward") forward();
    else if (voice == "backward") backward(); else if
    (voice == "left") left();
    else if (voice == "right") right();
    else if (voice == "stop") stopRobot();

    // -------- Cutter --------
      else if (voice == "cutter on") digitalWrite(cutter,
\HIGH);
     else if (voice == "cutter off") digitalWrite(cutter, LOW);

    // -------- Plough Servo --------
    else if (voice == "plough down") {
      ploughServo.write(0); delay(1000);
    }
    else if (voice == "plough up") {
      ploughServo.write(90); delay(1000);
    }

    voice = "";

  }
}
```

1.5. APP Terminal

Figure 1 Step-1 Playstore APP

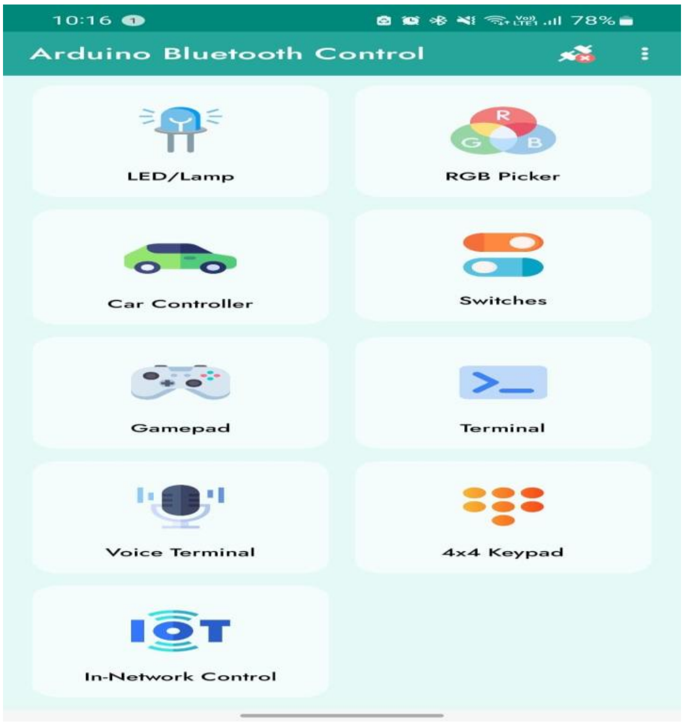

Figure 2 Step-2 Controlling commands

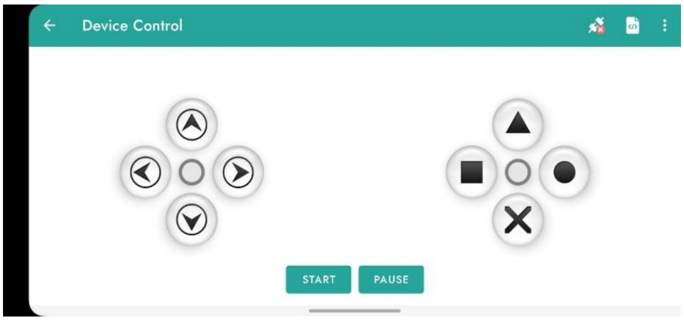

Figure 3 Step-3 Real Time Control

1.6. Prototype

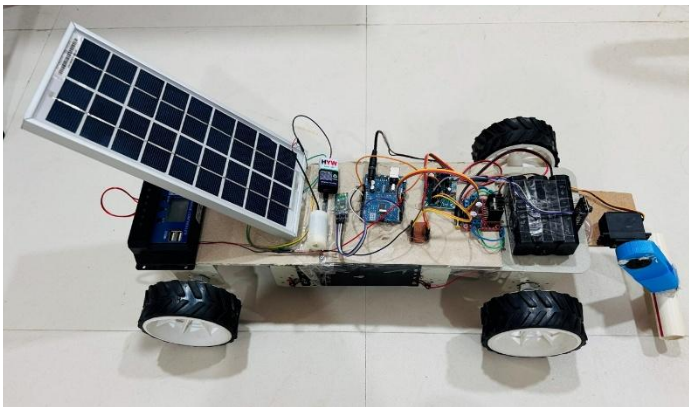

Figure 4 Hardware Kit

The proposed Smart Solar Powered Web- Controlled Multifunction Agribot addresses these limitations by combining renewable solar energy,low-cost embedded control, and multiple farming operations such as ploughing, seed sowing, watering,grass cutting and camera for real time monitoring and control into a single compact system. This integrated approach enhances efficiency while maintaining affordability and sustainability for small and medium-scale agricultural applications.

2. Results And Discussion

2.1.Result

The team conducted performance tests on the developed agribot by deploying it in actual agricultural environments[1] to assess its operational efficiency and measurement precision and system dependability. The system successfully executed all user commands which the testing team sent through the mobile application while it performed the designated agricultural tasks without any operational problems. The seed sowing mechanism placed seeds at uniform intervals, ensuring proper spacing required for effective crop growth. The irrigation system delivered controlled water flow to the required areas, which helped reduce water wastage and improved irrigation efficiency compared to traditional methods. The grass-cutting unit successfully eliminated small weeds together with all other unwanted vegetation, which resulted in the field area becoming both clean and easy to control. The solar power system continuously charged the battery during operation, which allowed the system to function without interruption for long periods because it did not need outside power sources. The study showed that agricultural automation systems achieve better performance when they use renewable energy sources. The mobile application established Bluetooth communication with the robot through the HC-05 Bluetooth module[2], which maintained connection stability during testing, so users could control the system without interruptions. The movement system employed DC motors which worked properly to create forward and backward and directional movement functions. The system maintained consistent performance, which remained stable throughout all operational functions. The system achieved better operational efficiency because different modules worked together to decrease the amount of manual work needed. The results show that the proposed agribot provides small and medium-scale agricultural operations with an economically viable and efficient solution which works well in areas that lack both labor and electricity resources[3].

2.2.Discussion

The following observations were recorded during field testing:

- Solar charging significantly extended the operating time during peak sunlight hours.
- Bluetooth communication remained stable within a 10 m line-of-sight range.
- PWM-based motor control improved smooth turning and reduced jerks during motion.
- Uniform seed placement was achieved when servo alignment was properly calibrated.
- Battery discharge rate increased when motors and pump operated simultaneously.
- Performance slightly degraded under cloudy weather due to reduced solar input.
- The robot navigated effectively on flat soil but experienced minor slip on wet terrain.

The integration of renewable energy with embedded automation demonstrates a practical approach to smart agriculture. While the system currently operates under manual control, its modular design allows seamless expansion toward autonomy and IoT integration. The experimental results validate that low-cost agricultural robots can deliver meaningful improvements in productivity and sustainability when properly designed. The system minimizes water wastage, while precise seed sowing improves crop yield efficiency. Overall, the system demonstrates that combining simple automation with renewable energy can significantly improve agricultural productivity[4]. The modular design of the agribot allows easy future upgrades without major changes to the existing setup. With further enhancements, the system can be scaled to support semi-autonomous or fully autonomous farming operations. This makes the proposed solution a promising step toward modern smart and sustainable agriculture[5 – 10].

2.3.Mathematical Calculations

This section presents the mathematical modeling and calculations used to validate the feasibility of the proposed Agribot:

2.3.1. Total Power Requirement

The total power consumed by the system is:

Assumed Values:

- $P_{motors} = 12V \times 0.6A = 7.2W$
- $P_{pump} = 12V \times 0.4A = 4.8W$
- $P_{controller+sensors} = 5V \times 0.1A = 0.5W$

2.3.2. Battery Backup Time

Battery backup time[11 – 15] is calculated as

$$T = \frac{C}{I_{load}}$$

Where:

- $C = 1.3Ah$
- $I_{load} = 1A$

$$T = \frac{1.3}{1} = 1.3 \text{ hours}$$

The robot can operate for approximately 1.3 hours without solar input.

2.3.3. Solar Panel Output Power

For a 12V, 10W solar panel:

$$I_{panel} = \frac{10}{12} = 0.83A$$

$$P_{solar} = 12 \times 0.83 = 9.96W \approx 10W$$

2.3.4. Charging Time Estimation

$$T_{charge} = \frac{C_{battery}}{I_{charging}}$$

Assuming charging current = 0.8A

$$T_{charge} = \frac{1.3}{0.8} = 1.62 \text{ hours}$$

2.3.5. PWM Duty Cycle for Motor Speed Control

$$\text{Duty Cycle (\%)} = \frac{T_{on}}{T_{on} + T_{off}} \times 100$$

This allows smooth control of motor speed.

2.3.6. Motor Torque Requirement

Where:

- F= Traction force
- r= Wheel radius

2.3.7. Solar System Efficiency

- $\eta = \frac{P_{out}}{P_{in}} \times 100$
- $\eta = \frac{7.5}{10} \times 100 = 75\%$

2.3.8. Equations Summary

- $P = V \times I$
- $P_{total} = \sum P_i$
- $T = \frac{C}{I}$
- $\eta = \frac{P_{out}}{P_{in}} \times 100$
- $\text{Duty Cycle} = \frac{T_{on}}{T_{total}} \times 100$

2.4.Performance Analysis

- The Smart Solar Powered Web Controlled Multifunction Agribot was successfully implemented.

$$P_{solar} = V_{panel} \times I_{panel}$$

- evaluated under real agricultural field conditions.
- The robot responded accurately to Bluetooth/web commands (forward, backward, left, right).
- The seed sowing mechanism achieved uniform placement with minimal clogging.
- The irrigation system reduced water wastage compared to manual methods.
- The grass-cutting unit effectively removed weeds and unwanted vegetation.
- The solar panel enabled continuous battery charging during operation in sunlight.

- Total Power Consumption = 12.5 W
- Battery Backup Time = 1.3 hours
- Solar Panel Output = 10 W
- Charging Time = 1.62 hour
- System Efficiency = 75%
- Total Current Draw ≈ 1.04 A

Conclusion

The proposed solar-powered multifunctional agribot provides an effective solution for automating agricultural tasks. By combining multiple operations into a single system, it reduces labor requirements and enhances productivity.The use of renewable energy makes the system cost-effective and suitable for remote areas. Remote control capability further improves safety and convenience for users.Future improvements may include GPS-based navigation, IoT integration, and advanced sensing technologies for smarter farming solutions. This work contributes to the advancement of sustainable and technology-driven agriculture.

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