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# Development of Solar-Powered Herbicide Spraying Robot Controlled Using a Mobile Application

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**Abstract:** The evolution of digital agriculture is significantly influenced by agricultural robots, which contribute uniquely and present numerous benefits to the efficiency of farming operations. The trend of population explosion that the world is experiencing mandates the need to provide an adequate food supply. Hence, a conscious effort must be taken to eradicate weeds on the farmland. This research explored the use of technology to implement a weed elimination system by combining IOT and wireless navigation while also implementing solar energy which encourages green energy initiatives. The research encompasses an unmanned ground vehicle driven by four wheels and controlled by a mobile application that establishes a Bluetooth connection with the system. The ground vehicle was tested to establish the solar charging efficiency, the mobile application connection and operation and the ground vehicle spraying action. The result obtained at the end of the research showed that remote controlled operation of agricultural robots can help improve production efficiency while also reducing environmental pollution with solar charging systems.

**Keywords:** agriculture; bluetooth; herbicide; mobile application; solar; weed

## 1 INTRODUCTION

Agriculture is a scientific discipline that employs contemporary technologies grounded in scientific methodologies and principles to enhance yield and production efficiency [1]. These scientific principles include crop breeding, crop protection, crop improvement and veterinary procedures for livestock and animals [2]. The natural rise in global population leads to heightened food demands, and projections indicate that by 2050, the world population may reach nine billion, necessitating a 70% increase in agricultural output [3]. Weeds pose a significant challenge in agriculture due to their unpredictable emergence and competition with crops for essential resources, ultimately leading to reduced crop yields [4]. Weeds emerge sporadically throughout the field, competing with crops for essential resources such as water, nutrients, and sunlight, potentially leading to negative effects on both crop yields and quality if not effectively managed [4-5]. Weed management involves various methods and strategies to control and reduce weed populations [6].

The demand for food is rising continuously, while conventional agricultural practices are proving inadequate. Additionally, the imperative of sustainable farm solutions has become critical in light of significant global issues like energy sustainability and migration crises [7]. The conventional approach to weed control in agriculture relies on manual labour and widespread herbicide application confronts significant issues, such as resource inefficiency and environmental degradation. Indiscriminate herbicide spraying not only escalates operational expenses but also raises ecological concerns, jeopardizing biodiversity [8]. Some farmers still use shoulder-mounted pesticide sprayers, which can release harmful pesticide residues into the air, posing health risks and potential fatalities [9].

The use of herbicides is common in agriculture that depends on agrochemicals, especially due to the promotion of genetically modified crops that can withstand herbicides [10]. The effectiveness of this application method is a major doubt due to how expansive some farmlands can be. Hence, an automated means of application is required. Solar power is incorporated into the system to explore the effective combination of green energy with robotics to solve the problem of herbicide application in agriculture. This integrated system offers more than efficiency; it harnesses solar energy, enabling independent operation in remote agricultural areas without traditional power sources. Powering onboard sensors and devices with solar energy allows this system to run continuously without frequent recharging, enhancing its scalability and adaptability in diverse agricultural settings. Solar energy stands out as a renewable energy source that is not constrained by limitations in agricultural production. Its applicability transcends factors such as property size, terrain configuration, and specific agricultural sectors [19]. Solar energy has the potential to meet global energy demands through environmentally friendly methods and at a reduced cost [20]. Many countries have not fully explored the potentials of solar energy [22].

Agrobot was designed by [11] for agricultural applications and represents a concept that, once optimized for performance and cost, is expected to enhance efficiency in agricultural spraying operations. The Agrobot is not cost effective and the concept design height is too low for real-life application [21]. Remote-controlled herbicide spraying systems are a better alternative to manual herbicide application as they factor in the health hazards associated with the manual application on labourers and farmers. The justification for this research is to develop a solar-powered herbicide spraying robot, managed through a mobile app to tackle agricultural labour shortages and supports sustainable, precision farming. This eco-friendly, cost-effective solution boosts efficiency, reduces chemical reliance, and prioritizes worker well-being.

## 2 MATERIALS AND METHODS

### 2.1 Hardware

The components required for the execution of this research are a buck converter, ESP 32 microcontroller module, Photovoltaic cell, relay module, ultrasonic sensor, DC motor, DC pump, charge controller, battery, connection cables, metallic frame, wheels, hose with nozzles and tank.

#### 2.1.1 ESP 32 Microcontroller

The ESP32 microcontroller (shown in Fig. 1 below) is a popular choice for Internet of Things (IoT) projects due to its low cost and power consumption, making it ideal for battery-powered devices. Its integration of Wi-Fi and Bluetooth capabilities allows for seamless connectivity to the internet and other devices, making it versatile for a wide range of applications. The dual-core Tensilica Xtensa LX6 microprocessor provides high performance and efficiency, allowing for the smooth operation of multiple tasks simultaneously.

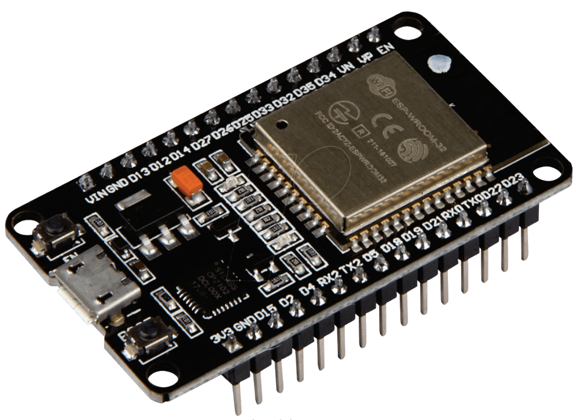

**Figure 1** ESP 32 microcontroller

**Figure 2** LM 2596 Buck Converter

#### 2.1.2 LM 2596 Buck Converter

The LM2596 regulator, shown in Fig. 2, is a monolithic integrated circuit designed for easy implementation of a step-down switching regulator (buck converter). It handles loads up to 3.0 A with excellent line and load regulation, featuring internal compensation to minimize external components. Operating at a 150 kHz switching frequency, it offers higher efficiency than traditional linear regulators, especially at high input voltages, and allows for smaller filter components. Available in a 5-lead TO-220 package and D2PAK surface mount option, it has a guaranteed output voltage tolerance of 4%, a 15% tolerance on oscillator frequency, and an external shutdown feature with a standby current of 80 µA. Protection features include cycle-by-cycle current limiting and thermal shutdown. Key specifications include an input voltage range of 3.2 V to 40 V, adjustable output voltage from 1.25 V to 35 V, maximum output current of 3A, up to 92% efficiency, output ripple below 30 mV, and an operational temperature range of –45 °C to +85 °C, with dimensions of 43.2 × 21.0 × 14.0 mm [16-17].

#### 2.1.3 Photovoltaic Cell

Photovoltaic cells also known as solar panels (see Fig. 3) are devices that convert sunlight into electrical energy, providing an alternative power source for the system. Photovoltaic (PV) cells, also known as solar cells, are tiny power generators that convert sunlight directly into electricity. When sunlight hits the PV cell, photons (light particles) are absorbed by a semiconductor material, typically silicon. The absorbed photon energy excites electrons within the semiconductor, freeing them from their atoms. Imagine bumping an electron with enough force to break it free from its usual spot. These freed electrons don't want to stay put. Due to an internal electric field within the cell, it starts to flow through it, creating an electric current. This flow of electrons constitutes electricity that can be used to power electronic devices. This movement of electrons is what we use as electricity.

**Figure 3** Photovoltaic cell

**Figure 4** 12 V AD20P DC Pump

#### 2.1.4 DC Pump

The DC pump (see Fig. 4) is an electromechanical device that helps transmit fluid from one point to another by creating a differential pressure due to a voltage change. The AD20P DC pump 12 V has a brushless permanent magnetic rotor and a very efficient running life of more than 30,000 hours. It features a highly efficient ceramic shaft to reduce wear and tear, and it employs static sealing instead of dynamic to minimize any leaking problems. The design is flexible to allow the pump to be submerged and fully water-tight while being energy-saving and low noise-emitting at less than 35 dB. It functions with a 12 V input voltage, which can be supplied either from batteries or from solar panels.

### 2.1.5 DC Motor

The DC electric motor (shown in Fig. 5) is an electrical machine that converts electric power into mechanical energy. The DC motor is the prime mover of the unmanned vehicle. The specification are as follow:
Voltage: 12 V
- Weight: 310 g
- Motor diameter: 37 mm
- Output shaft length: 21mm
- No load speed: 2000 rpm
- Ratio: 1:6.3.

**Figure 5** DC Motor

### 2.1.6 Relay Module

A relay is an electromagnetic switch that opens or closes an electrical circuit when activated by an electric current. A relay module (shown in Fig. 6) is a component that includes a relay mounted on a board with other elements to provide isolation and protection. Its main function is to switch electrical devices on and off, while also isolating control circuits to ensure safety. The relay can be triggered by different voltage signals like 3.3 V or 5 V, making them versatile for use in controlling the pump and DC motors.

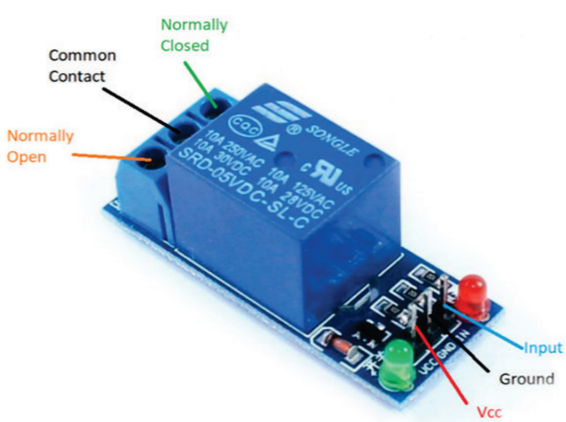


**Figure 6** Relay module

### 2.1.7 Battery

The battery, shown in Fig. 7, converts chemical energy into electrical energy, powering the system. This system will use a rechargeable battery with a voltage of 12 V to support its various components. The other specifications of the battery are:
- Capacity: 7.5 Ah
- Weight: 0.64 kg

**Figure 7** Battery

## 2.2 Software

### 2.2.1 Mobile Application

The mobile control application was created using MIT App Inventor, a user-friendly visual programming tool from the Massachusetts Institute of Technology (MIT) that allows users with little programming experience to develop Android apps [18]. It features a drag-and-drop interface for building applications with functional blocks. The platform includes a designer layout for the user interface and a block layout for backend operations with the microcontroller. It also supports non-visible components like Bluetooth and Wi-Fi for communication with the ESP32 module used in the research. The mobile application front page layout is shown in Fig. 8 below.

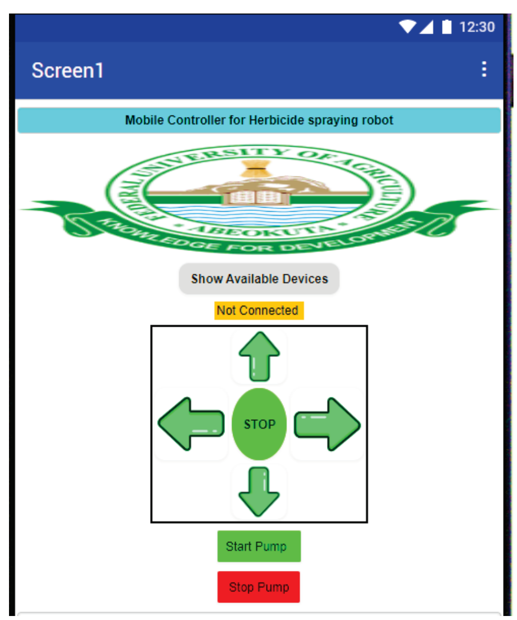


**Figure 8** Mobile application layout

## 2.3 Construction and Assembly of Chassis Frame

The chassis was developed utilizing PTC Creo 9.0 parametric software, incorporating all essential parameters. Fig. 9 illustrates the isometric and lateral views of the CAD model. The chassis structure was constructed from L-shaped metals, which were assembled through arc welding.

## 2.4 Overview

The system consists of an electrical circuit that controls the robot's movement and pump function, powered by a rechargeable 12 V battery charged via a solar cell and managed by a charge controller to prevent overcharging. The controller has indicators for battery status and a switch to deactivate the circuit. A boost converter ensures a stable 5-volt output for the ESP32 control unit, which manages inputs and outputs. The motor control relays use 4 of the ESP32's 40 GPIO pins to control four motors for speed and direction. Additionally, a relay module and ultrasonic sensors are connected for pump control and level measurement. The circuit diagram was created using Kicad software, as shown in Fig. 10.

**Figure 9** 3D CAD model of the chassis

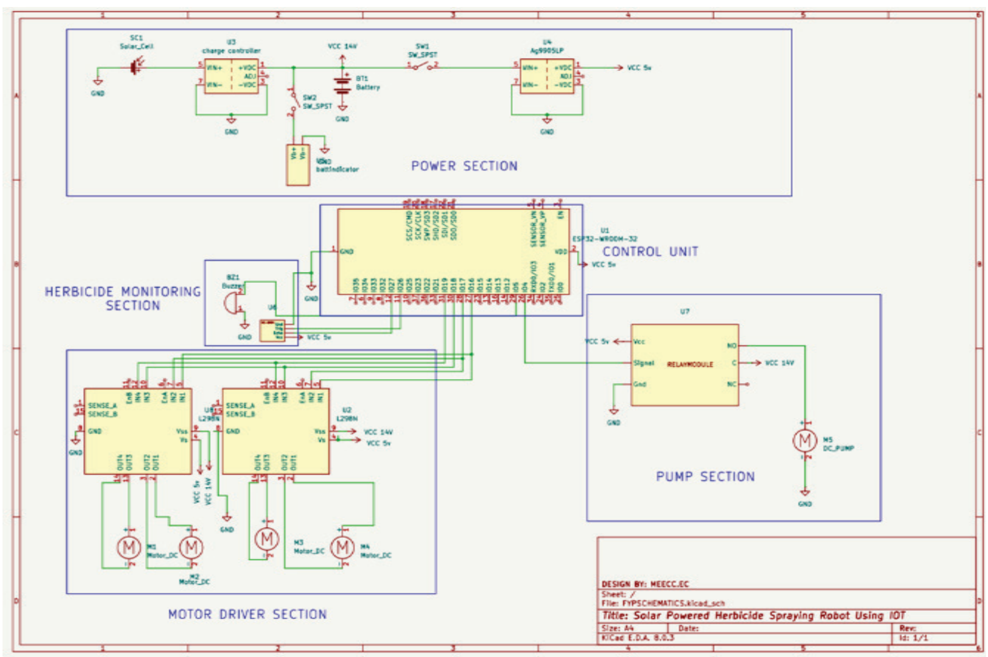


**Figure 10** Circuit Diagram

## 2.5 Design Calculation

### 2.5.1 Weight Consideration

The power required to operate the system relies on the characteristics of the DC motors utilized for wheel propulsion [12, 13] stem is approximately 8 kg. Hence, selecting the right driving motor that fits the system's functionality is imperative.

$$P = I \cdot V, \tag{1}$$

$$P = m \cdot g \cdot \frac{2\pi \cdot N}{60}, \tag{2}$$

where: $P$ – electric power (W), $I$ – current rating of motor (A), $V$ – voltage rating of the system (V), $m$ – mass to be driven by the wheel (kg), g – acceleration due to gravity (approximately 10 m/s$^2$), $N$ – speed of the motor (rpm).

The weight of the motor can calculate by Eq. (3).

$$W = m \cdot g = \frac{60 \cdot P}{2\pi \cdot N} = \frac{60 \cdot I \cdot V}{2\pi \cdot N}. \tag{3}$$

Considering the specification of the motor: $V = 12$ V, $I = 5$ A and $N = 75$ rpm.

Substituting into the Eq. (3),

$$W = \frac{60 \cdot 12 \cdot 5}{2\pi \cdot 75} = 8 \text{ kg}.$$

Since two motors are considered, the total weight will be 16 kg, up to the required rating.

### 2.5.2 Power Calculation

The power consumption of each component (shown in Tab. 1) was calculated using the power formula to determine if the battery choice would be able to power all the selected components.

**Table 1** Power consumption.

| Component | Voltage (V) | Maximum Current (A) | Power (W) |
|---|---|---|---|
| Motor (2 units) | 9 | 2 | 36 |
| Pump | 12 | 0.3 | 3.6 |
| ESP 32 module | 3.5 | 0.21 | 0.735 |
| Relay (3 units) | 3.5 | 0.02 | 0.21 |
| Buzzer | 3.5 | 0.02 | 0.07 |
| LCD screen | 3.5 | 0.02 | 0.07 |
| TOTAL | | | 40.685 |

The total power supplied by the battery is 90 W. Hence, the battery is sufficient to power the system.

## 3 TESTING AND RESULT

The completed setup (as shown in Fig. 11) was put to test to determine if the aims of the research was achieved. The mobile application connection, charging via the photovoltaic cell, the vehicle motion and the spraying action were all tested.

**Figure 11** Research Prototype

### 3.1 Mobile Application Connection

The following steps are taken to connect the mobile application to the robot after installing on the mobile device:

1) Use Bluetooth to pair to the ESP 32 module named "ESP32test".
2) Open the mobile application and select the "Connect device" button.
3) Navigate through the available devices option and select "ESP32test".
4) The ESP32 module will immediately connect to the application and the connection status on the mobile application will be changed to "connected".
5) The buttons on the mobile application can be clicked to navigate the robot in any direction as required. The "start pump" and "stop pump" buttons are used to control the spraying action of the herbicide.

The function of each button implemented on the mobile application is shown in Tab. 2 below.

**Table 2** Table showing the functions of the buttons present on the mobile application

| S/N | Button | Function |
|---|---|---|
| 1 | Forward arrow | When clicked, this actuates the motors to move forward. |
| 2 | Reverse arrow | When clicked, this causes the motors to move backwards. |
| 3 | Left arrow | When clicked, this causes the motors to move to the left. |
| 4 | Right arrow | When clicked, this causes the motors to move to the right. |
| 5 | Stop | When clicked, this stops the motors bringing the vehicle to a halt. |
| 6 | Start Pump | When clicked, this actuates the pump to spray the herbicide |
| 7 | Stop Pump | When clicked, this turns off the pump and spraying stops. |

### 3.2 Photovoltaic Cell Charge Testing

The power rating of the selected solar panel is 8 W. The voltage output collected at 11:26 GMT under a temperature of 28℃ was 16.72V. This was collected by connecting a voltmeter to measure the result. This voltage was sufficient enough to charge the battery. The effectiveness of a solar panel depends on various factors, including its orientation, angle, sunlight exposure, temperature, shading, and the electrical load it's connected to [14]. The performance ratio of the photovoltaic cell is proportional to the incoming radiation on the surface which also corresponds to the quantity of electricity it supplies [23]. The charging rate of the photovoltaic cell will vary under different environmental conditions. Tab. 3 below shows the relationship between the sunlight intensity and current. Figs. 12 and 13 show the graph of light intensity against average power output supplied by the photovoltaic cell.

**Table 3** Table showing the relationship between the light intensity and current supplied by the solar cell

| Light Intensity (W/m²) | Charging Current (A) |
|---|---|
| 200 | 0.13 |
| 400 | 0.27 |
| 600 | 0.40 |
| 800 | 0.53 |
| 1000 | 0.67 |

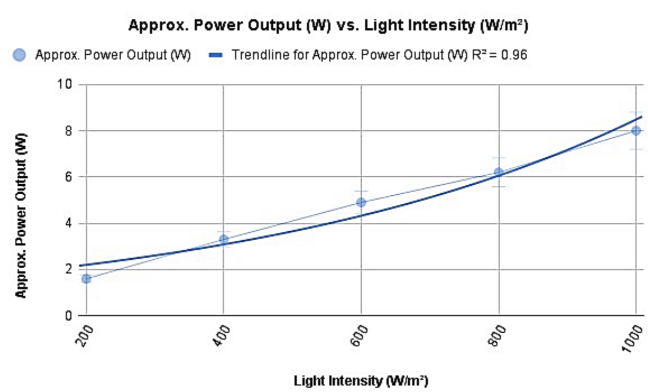


**Figure 12** Graph showing the light intensity vs approximate power output

### 3.3 Spraying Test

The sprayer was implemented with three nozzles to spray a larger cross-section area during the spraying action. The effective flow rate of the pump is 1 L/min. Hence, the flow rate at each nozzle will be 1/3 L/min. The spraying action is immediately activated at the tap of the "start pump" button and it is deactivated at the tap of the "stop pump" button.

### 3.4 Motion Test

The vehicle's motion was tested on different terrain to observe its speed. The tests were carried out on three different terrains which are: smooth surface floor, rough surface and a low growing lawn. Each surface exhibits distinct properties that can affect the motion of an object, including factors like friction, resistance, and texture. The objective of comparing these different conditions was to analyze how surface characteristics influence the object's speed, travel distance, and overall dynamics of motion. Tab, 4 below shows the time taken to cover similar distance on each surface and Fig. 13 shows a bar chart of the time taken on the different test terrain for the same area.

**Table 4** Table showing the time taken to cover an area of 3m$^2$ on different terrain.

| S/N | Terrain | Area (m$^2$) | Time (s) |
|---|---|---|---|
| 1 | Smooth surface Floor | 3.0 | 5.1 |
| 2 | Rough Surface | 3.0 | 7.3 |
| 3 | Low Growing Lawn | 3.0 | 13.3 |

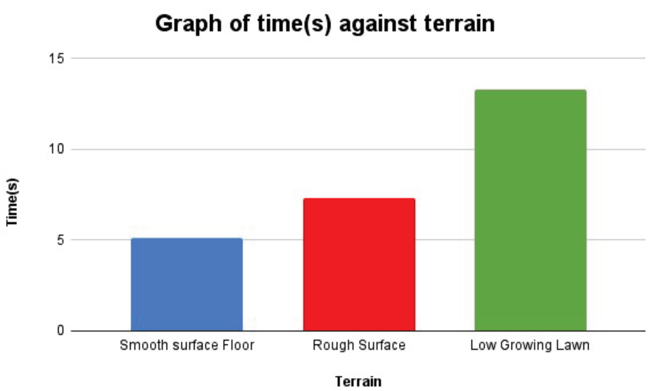


**Figure 13** Bar chart showing the time taken to cover the same area on different terrains

## 4 CONCLUSION AND RECOMMENDATION

A comprehensive assessment of all system functions was performed to validate their alignment with the research's defined goals and objectives. The mobile application, created through the MIT Inventor online platform, effectively interfaced with the robot via a Bluetooth module connected to the ESP 32. This configuration was instrumental in navigating the research course and controlling the pump that facilitated the transfer of herbicide to the nozzles for the purpose of weed elimination in agricultural fields. To augment the system's functionality, several recommendations can be considered:

- Integrating Wi-Fi alongside Bluetooth to enhance connectivity in environments prone to interference.
- Utilizing computer vision for accurate navigation, which would enable real-time trajectory modifications for optimal coverage.

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