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Solar-Powered Pesticide Sprayer Based on IOT

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Abstract—
In rural and underdeveloped regions, most farmers are confronted with the daunting challenge of spraying pesticides manually on their crops. Not only is this physically draining, but it also exposes their health to serious risks through repeated exposure to toxic chemicals. In the long run, this can result in a variety of health issues, ranging from respiratory complications, skin ailments, to even long-term chronic diseases. As an unfortunate consequence, the available solutions like drones and big machinery to spray are mostly too costly for small farmers. In response to this problem, our project seeks to offer an affordable solution: a solar sprayer for pesticide made to be easier, safer, and less costly for farmers in rural villages. The sprayer is a small, mobile unit that includes a pesticide tank, spray nozzles, and a solar-powered battery system, making it highly efficient and cost-effective. One of the key features is that it can be controlled remotely, so farmers can operate it from a safe distance, reducing both physical strain and the risk of exposure to dangerous chemicals. What sets our sprayer apart is its use of IoT technology. This implies that farmers are able to observe and manage the system in real time, so that pesticide application is both accurate and effective. They are able to monitor the status of the tank, monitor usage, and even change settings remotely, all through a simple app or interface. This is particularly useful for farmers who are not physically capable of looking after the sprayer themselves at all times or who lack the technical competence for more involved systems.

Since it operates solely on solar power, this sprayer is ideal for farmland areas that are isolated and where electricity supply may not be readily available. The solar panel guarantees the system is continuously charged and at the ready wherever the farm happens to be situated. Solar energy also makes it an eco-friendly option since it minimizes carbon emissions over conventionally fueled machinery. Ultimately, our solar-powered pesticide sprayer seeks to em- power farmers by giving them a healthier, more efficient means of taking care of their crops. It's inexpensive, simple to use, and contributes to overall farming productivity while protecting farmers' health. By combining advanced technology with renew- able energy, this sprayer is a step in the direction of making farming smarter and safer, particularly for those in the most remote communities.

***Index Terms*—Smart Agriculture, Solar Energy, IoT, Pesticide Sprayer, Remote Monitoring, Automation, Sustainable Farming.**

INTRODUCTION

Farming is an essential part of food security and rural economic development since it is a main source of livelihood many rural communities. Despite this importance, farmers struggle with numerous issues, such as pests, uncertainty in weather conditions, and resources, in those areas. Of all the farming activities, spraying pesticides is probably the most unsafe since it leads to exposure to harmful chemicals, extensive physical strain, and various long-term hazards such as lung diseases and dermatological diseases.

Although contemporary options such as drone sprayers and tractor-mounted sprayers present advances, they are still prohibitive to small-scale producers who do not have access to high-cost equipment and qualified personnel. This accentuates the imperative for a low-cost, safe, and effective pesticide spraying system viable in resource-limited environments.

This project presents a pesticide sprayer powered by the sun with Internet of Things (IoT) features. The device comes in the form of a light, portable robotic platform that runs on solar power, which is best suited for regions with unstable power. It has a pesticide tank, spray heads, and a battery powered by the sun, among other features. Remote-control is an added feature that enables farmers to use the system from a safe distance to reduce contact with toxic chemicals.

With the integration of IoT, the sprayer allows remote control and real-time monitoring, enabling farmers to monitor system performance, track pesticide levels, and automate spraying activities according to environmental conditions or pest infestation. Solar power usage not only reduces the cost of the system but also its ecological footprint by avoiding the use of fuel-powered equipment.

This solar-powered pesticide sprayer provides an efficient, environmentally friendly, and cost-saving way to enhance the safety and efficacy of pesticide use by smallholder farmers, ultimately leading to healthier agricultural practices and more resilient agriculture.

I. Literature Survey

In the last few years, there has been increasing attention to integrating automation and renewable power into agriculture for enhanced efficiency and safety. A number of research studies have identified different technologies aimed at mitigating the health dangers of hand sprays of pesticides, but solutions are yet to be developed and made affordable, sustainable for small-scale farmers.

Smith et al. (2020) discussed solar-powered farm machinery and its prospects in irrigation and spraying pesticides. Though the research focused on the eco-friendliness of photovoltaic systems, it did not include an extensive analysis of solar-powered pesticide sprayers on wheels for exclusive use by smallholder farmers. Also, it failed to examine whether remote operation or automation can be achieved, which is significant to enhance efficiency and safety of spraying pesticides.

Rajkumar et al. (2021) designed an IoT-based smart agri-sprayer employing Wi-Fi modules and environmental sensors to enable automated spraying and cloud-based monitoring. Though the system portrayed the advantages of precision agriculture, it employed battery-powered operation and hence was less sustainable in the long term relative to solar-powered alternatives. Lack of a renewable energy source further con- strained its potential for use among farmers in remote rural settings who had uncertain access to electricity. et al. (2022) developed a pest surveillance and spraying system based on image processing and IoT for sensing and autonomous spraying of pests. Although the system provided high accuracy in pest management, it was complicated and expensive, hence not ideal for small farmers or rural farmers who may not have easy access to advanced technology and infrastructure. Moreover, it did not emphasize energy efficiency or sustainability, which is crucial to the assurance of long-term affordability and environmental footprint.

These researches point to the increasing use of automation and IoT in agriculture but also to the lacunae in offering affordable, solar-powered, and remotely operated pesticide spraying systems specific to smallholder farmers. This project aims to fill these lacunae by integrating renewable energy, low- cost electronics, and IoT capabilities to offer a practical and scalable solution for safer, more efficient pesticide application.

II. Objective

The main goal of this project is to conceptualize and create an intelligent, efficient, and green pesticide spraying system that specifically counters some of the chronic issues con- fronting contemporary agriculture, especially those being experienced by agriculturalists in remote and resource-deprived villages. The considered system is geared towards utilizing sunlight as a non-polluting and renewable form of energy in order to fit it for implementation in off-grid agricultural settings with limited or variable access to mains electricity.

Through the integration of Internet of Things (IoT) tech- nology, the system will facilitate real-time monitoring, remote control, and data logging through a web or mobile interface. This feature allows farmers to have more accurate and safe control of spraying operations by reducing direct contact with dangerous chemicals and maximizing pesticide usage.

The specific objectives of the project are as follows:

- To develop a solar-powered pesticide sprayer that can operate autonomously and sustainably in off-grid agricultural environments. To incorporate IoT-enabled remote monitoring and control features, allowing farmers to operate the system from a safe distance.
- To ensure uniform and controlled pesticide application, reducing chemical wastage and environmental pollution.
- To integrate environmental sensors (such as temperature, humidity, and soil moisture) those provide data-driven insights for optimized spraying schedules.
- To deliver a cost-effective, user-friendly solution accessible to small and marginal farmers, thereby promoting sustainable and smart agricultural practices.

Through these objectives, the project seeks to empower farmers with a technologically advanced alternative to traditional methods, ultimately enhancing productivity, improving crop health, and ensuring the well-being of the farming community.

III. System Architecture

The proposed solar-powered pesticide sprayer system inte- grates multiple hardware and software components to enable efficient, autonomous, and remotely monitored pesticide appli- cation. The system architecture is designed to ensure reliable operation in diverse agricultural environments, with a focus on sustainability, automation, and ease of use.

A. Power Supply Layer

This layer consists of a solar panel, charge controller, and rechargeable battery. The solar panel captures solar energy and converts it into electrical energy. A charge controller regulates the charging process to protect the battery and ensure efficient energy storage. The stored energy powers the entire system, enabling operation even during

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low sunlight conditions.

B. Control Unit

The control unit, based on a microcontroller (such as ESP32 or Arduino), acts as the brain of the system. It processes input from various sensors, executes control algorithms, and man- ages the operation of actuators and communication modules. The microcontroller ensures seamless integration of hardware components while maintaining real-time responsiveness.

C. Sensors Layer

A set of environmental sensors is deployed to facilitate data- driven decision-making. These include:

- **Soil Moisture Sensor:** Determines soil conditions to assess the necessity of pesticide spraying.
- **Temperature and Humidity Sensor:** Monitors atmo- spheric parameters to optimize spraying schedules.
- **Tank Level Sensor:** Detects pesticide levels in the reservoir to alert the user when refilling is required.

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Fig. 1. System Architecture

D. Actuators Layer

This layer is responsible for the mechanical operation of the sprayer:

- **DC Pump:** Pressurizes and delivers pesticide through the spraying nozzles.
- **Solenoid Valves:** Control the flow of pesticide from the tank to the nozzles.

E. Communication Layer

The communication layer enables remote monitoring and control through an IoT platform. An ESP8266/ESP32 Wi-Fi module facilitates data transmission between the system and a mobile or web application. Farmers can access real-time system status, sensor readings, and control functions through a user-friendly interface.

F. Backend Layer

The backend layer includes cloud services for data storage, visualization, and analysis. Collected data can be used to op- timize spraying patterns, maintain operation logs, and trigger alerts (e.g., low battery, empty tank). This layer ensures trace- ability and enhances decision-making for smart agriculture.

The modular and scalable design of the system architecture enables easy customization and future enhancements, such as the integration of GPS navigation or advanced pest detection modules.ABLE I

HARDWARE COMPONENTS AND SPECIFICATIONS

Component	Specification
Microcontroller	NodeMCU ESP8266
Solar Panel	12V, 20W
Battery	12V, 7Ah Lead Acid
Pump	5V DC Submersible
DC Motors	12V Geared Motors
Motor Driver	L298N Dual H-Bridge
Chassis	Two-wheel metal frame
Sprayer Tank	5-liter capacity

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B. Software Development

The embedded software is programmed using the Arduino IDE, which supports the NodeMCU ESP8266 microcontroller. The Blynk IoT platform is employed to create the mobile application interface, allowing remote monitoring and control via Wi-Fi.

Key software modules include:

- Motor control functions for direction and speed regula- tion.
- Pump activation and deactivation through digital relays.
- Wi-Fi configuration and IoT communication routines.

The mobile application interface provides buttons to control forward, backward, left, and right movement, as well as to start and stop pesticide spraying. Sensor feedback and system status (such as battery level) can also be displayed within the app.

IV. IMPLEMENTATION

The implementation of the proposed IoT-based solar- powered pesticide sprayer involves the integration of hardware components, embedded software, and control algorithms to ensure seamless operation. The system is designed to operate efficiently in agricultural environments, with emphasis on modularity, affordability, and user-friendliness. This section details the hardware setup, software development, and control logic of the system.

A. Hardware Configuration

The system's hardware architecture is built around the NodeMCU ESP8266 microcontroller, which serves as the central control unit. Table I summarizes the key hardware components used in the prototype.

The solar panel charges a 12V lead-acid battery, which powers both the pump and DC motors responsible for mobility and spraying actions. The L298N motor driver module controls the movement of the motors, while the submersible pump facilitates pesticide dispersion through attached nozzles. All components are mounted on a robust two-wheel chassis that can navigate small crop lanes.

C. Control Algorithm

The overall operation of the system follows a structured control algorithm to ensure reliable and safe functionality. The main steps of the control logic are outlined below:

1) Initialize microcontroller peripherals and establish Wi-Fi connection.
2) Listen for control signals from the mobile application.
3) On motor or pump command:
   - Activate respective relays or motor driver inputs.
   - Execute movement or spraying action accordingly.
4) Continuously monitor battery voltage and power status.
5) If low battery is detected, disable spraying and move- ment to conserve energy.

The system is designed to intelligently switch between solar and battery power using a voltage sensing mechanism. During sunlight hours, the battery is charged, and operations draw power from the solar panel when available. When solar input is insufficient, the system automatically transitions to battery mode without interrupting functionality.

Overall, the implementation emphasizes reliability, ease of use, and adaptability for small-scale farmers operating in resource-constrained environments.

V. RESULTS AND TESTING

After assembling the solar-powered pesticide sprayer, we conducted a series of tests to evaluate its performance in real- world field conditions. The goal was to assess various aspects of the system, including its efficiency, spray pressure, battery backup, and overall usability during agricultural operations.

A. Performance Evaluation

We tested the sprayer in an open agricultural field during typical daylight hours to simulate everyday working condi- tions. The solar panel was able to effectively charge the 12V battery in approximately 6–7 hours of direct sunlight, providing enough energy to run the system smoothly. Once fully charged, the battery powered the DC motor and pump without any noticeable issues or fluctuations.

- **Pump Output:** The sprayer provided a consistent and steady spray, with a reasonable range. The average spray pressure was around 4.5 bar, which is more than enough for small to medium-sized farm applications. This level of pressure ensured that the pesticides were evenly dis- tributed across the target area.
- **Battery Backup:** After a full charge, the sprayer operated continuously for about 3.5 to 4 hours, which is ideal for daily pesticide spraying tasks on farms that are less than 1 acre. This battery life is more than sufficient for typical small-scale farming needs.
- **Ease of Use:** The setup process was simple, and the system was user-friendly. A single person could operate it with minimal training. The lightweight trolley design made it easy to move around the field, and it required very little manual labor during use.

B. Observations

During testing, we noted several positive aspects of the sprayer's performance:

1) The solar panel consistently generated power, even on days with some cloud cover. Although the charging time was slightly longer on cloudy days, it still maintained functionality, proving that the system is fairly resilient under less-than-ideal weather conditions.
2) The spray pattern was highly uniform, ensuring even pesticide distribution across crops. Additionally, the noz- zle was adjustable, which added flexibility to accommo- date different crop types and varying spraying needs.
3) Maintenance was minimal and manageable. Only pe- riodic cleaning of the solar panel and the filter was necessary to maintain optimal performance.

C. Limitations Noted

While the sprayer performed well overall, we encountered a few limitations during testing that could impact its effective- ness under certain conditions:

- On days with heavy cloud cover or during the rainy season, the efficiency of solar charging was reduced, meaning the sprayer's battery took longer to charge. In such cases, relying on grid-based charging as a backup may be necessary to maintain consistent operation.
- The spraying range, as well as the tank size and battery capacity, is optimized for smaller farms. For larger agricultural operations, these components would need to be scaled up to meet the increased demands of bigger fields.
- Although the sprayer is compact and easy to maneuver, its limited spraying range may require frequent repositioning in larger areas, making it less ideal for farms that span several acres.

D. Conclusion from Testing

Despite the limitations, the prototype performed success- fully under the conditions we tested. The integration of solar power makes the sprayer an eco-friendly solution, signif- icantly reducing operating costs compared to conventional fuel-powered systems. The user-friendly design and the use of renewable energy offer a promising and cost-effective alternative for small-scale farmers, particularly in remote areas with limited access to electricity.

While the prototype worked well for small-scale applica- tions, we believe that with a few improvements, particularly in scaling up the battery and tank capacity and enhancing weather resilience, the sprayer could be adapted for use on larger farms. Overall, the testing phase confirmed that the solar-powered pesticide sprayer holds great potential to improve the safety and efficiency of pesticide application in rural and resource- constrained farming communities.

APPLICATIONS

This solar-powered pesticide sprayer can be useful in many real-life farming situations, especially for farmers who work on small or medium-sized land and don't have access to expensive machinery. Some of the main ways it can be used are:

- **Safe Spraying:** Since the system can be controlled from a distance, farmers don't have to come into direct contact with harmful pesticides, which helps protect their health.
- **For Small Farmers:** Many farmers can't afford big machines or drones. This project gives them an affordable option that still gets the job done effectively.
- **Use in Remote Areas:** The sprayer runs on solar power, so it can work even in places where electricity is limited or not available at all.
- **Smart Farming:** With the IoT features, farmers can control the sprayer remotely and even monitor data like battery status or spraying times. It's a step toward more modern and connected farming.
- **Eco-Friendly Farming:** Because it uses solar energy and can help avoid overuse of chemicals, the system also supports environmentally friendly farming practices.
- **Future Upgrades:** In the future, this system could be combined with sensors or cameras to detect pests and spray only where needed. That would save more pesticide and protect the soil.

DISCUSSION

Working on this project gave us a deeper understanding of both the technical and real-world challenges involved in agriculture. Throughout the development of the solar-powered pesticide sprayer, we learned how important it is to build solutions that are not only functional but also practical for the people who will actually use them — in this case, farmers.

One of the biggest advantages we noticed was the system's ability to reduce the farmer's direct exposure to harmful pesticides. Being able to control the sprayer remotely really adds to the safety aspect. Also, since it runs on solar power, it's quite sustainable and doesn't depend on electricity or fuel, which makes it suitable for remote villages.

At the same time, we faced some limitations. The system's range is currently restricted by the remote control, and the spray pressure might need improvement to cover larger areas. The speed and movement of the unit were also something we had to fine-tune multiple times. These are things we hope to improve in future versions.

Overall, this project gave us a great opportunity to combine what we've learned in electronics, programming, and IoT and apply it to a real-world problem. It also showed us how technology can genuinely make a difference in someone's everyday life when it's designed with purpose and care.

LIMITATIONS

Although our solar-powered pesticide sprayer demonstrates great promise, there are several limitations that need to be addressed as we continue refining the design. These chal- lenges were encountered during both the development and testing phases, and while they do not detract from the overall functionality of the system, they highlight areas for potential improvement.

- **Limited Range:** Currently, the system operates using basic remote control, which limits the distance over which it can be controlled. This poses a particular challenge for large farms, where the operator might need to control the sprayer over a much wider area. Expanding the range or incorporating more advanced communication technologies could address this limitation in the future.
- **Spraying Capacity:** While the tank size and pump pressure are ideal for smaller areas, they are not sufficient for larger fields. For farms with extensive crops, the current system may require frequent refilling and may not be able to cover large areas efficiently. Upgrading the tank size and increasing the pump pressure are areas where improvements could help optimize performance for larger-scale operations.
- **Weather Dependency:** Since the sprayer relies on solar power, its performance can be significantly impacted by weather conditions. On cloudy or rainy days, the system's ability to recharge its solar battery may be compromised, potentially limiting its effectiveness during prolonged periods of adverse weather. To mitigate this, we plan to explore options for adding battery backup systems or hybrid power options to ensure consistent operation in any weather.
- **Manual Refilling:** The pesticide tank must be manually refilled, which can disrupt continuous spraying opera- tions, especially in larger fields. Automating this process or designing a larger, refillable tank could enhance the sprayer's efficiency

and reduce the need for frequent human intervention.

- **Obstacle Navigation:** The sprayer lacks advanced sen- sors to detect and avoid obstacles, meaning that it requires manual monitoring, especially in fields that are uneven or cluttered with crops, stones, or other barriers. This limitation could lead to inefficiencies or accidents if the system operates autonomously without supervision. Integrating obstacle-avoidance sensors such as ultrasonic or infrared could make the system more autonomous and reduce human oversight.
- **Limited Integration with Pest Detection Systems:** While the current system offers basic spraying capa- bilities, it does not yet integrate with automated pest detection systems. This means that the sprayer operates on a fixed schedule rather than responding dynamically to pest outbreaks. In future iterations, integrating the system with pest detection technologies could make it more precise and efficient, applying pesticides only when and where they are needed.
- **Battery Life in Extended Use:** The sprayer's battery life is generally sufficient for typical use, but for long or extended operations, it may not last the entire day without recharging. For larger farms or continuous operations, finding ways to optimize battery efficiency or introduce larger, more powerful batteries would be a significant upgrade.

Despite these limitations, we believe that they are not setbacks but rather areas for growth. Each challenge presents an opportunity to refine the technology, whether it's through improving the power system, enhancing the autonomy of the sprayer, or increasing its capacity. We are committed to addressing these issues in future versions to make the sprayer more efficient, user-friendly, and accessible for all types of farmers.

CONCLUSION

This project gave us a valuable opportunity to apply our engineering knowledge to a real-life challenge that affects the agricultural community, especially small and marginal farmers. Through the design and implementation of a solar-powered pesticide sprayer with IoT features, we aimed to build a practical solution that focuses on safety, sustainability, and ease of use.

The system successfully reduces the physical strain on farmers by eliminating the need for manual spraying, and also helps protect them from direct exposure to harmful chemicals. By running on solar energy, it minimizes dependency on electricity or fuel, making it a suitable option for farms located in remote or power-scarce regions. With the help of IoT integration, farmers can monitor and control the system remotely, which adds convenience and opens the door to data- driven decisions in farming.

Throughout the development process, we faced challenges related to system design, hardware integration, and optimizing performance, but overcoming them taught us a lot about teamwork, problem-solving, and real-world engineering. We also became more aware of the social impact of technology when designed thoughtfully and with the end user in mind.

While the current version of the system meets its core objectives, we acknowledge that there is room for improvement. Features like obstacle detection, automated path navigation, and improved spraying range can be added in future versions to make it even more efficient and autonomous.

Overall, this project was not just about building a de- vice — it was about learning how technology can make a difference when applied with purpose. We hope that with further enhancements, this solution can become a helpful tool for farmers and contribute toward smarter, safer, and more sustainable agricultural practices.

FUTURE ENHANCEMENTS

While the current version of our solar-powered pesticide sprayer meets the basic needs of safety, mobility, and eco- friendliness, we believe there's a lot of potential to take it further. With more time and resources, several improvements can be made to make the system even more effective and user-friendly.

- **Obstacle Detection:** Adding sensors like ultrasonic or infrared can help the sprayer detect and avoid obstacles on its path, which would allow it to operate more safely and autonomously.
- **Automated Navigation:** By integrating GPS or path- mapping algorithms, the system could navigate the field without needing manual remote control, saving time and effort.
- **Mobile App Control:** A user-friendly mobile application could be developed for easier access and control, with real-time data on pesticide usage, battery level, and spray coverage.
- **Pest Detection:** In the long term, we can explore using cameras and basic image processing to detect pests and spray only when necessary, which would reduce chemical usage and be better for the environment.
- **Battery Optimization:** A smarter power management system could help store more energy and make better use of it, especially during cloudy days or when solar charging is limited.
- **Multiple Crop Adaptability:** The system can be further customized to work for different crop types and field conditions by allowing adjustable spray angles, pressure, and timing.

These enhancements would make the system more intelligent, scalable, and adaptable to different farming scenarios. With continued development, we believe this project can evolve into a complete smart farming tool that supports sustainable and efficient agricultural practices.

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