

# Smart Coastal Sprayer For Small Scale Farmers Using Wind-Assisted Battery Charging

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**Abstract-** Traditional pesticide spraying in coastal regions suffers 40-60% wastage due to unpredictable wind patterns. This paper introduces an ESP32-based autonomous sprayer integrating wind turbine battery charging, real-time anemometer monitoring, and MPU6050 stabilization. The wind-aware adaptive algorithm dynamically adjusts nozzle angle and spray rate based on wind velocity/direction, achieving 42% chemical savings and 91% coverage uniformity. The system enables small-scale farmers (<5 acres) to access precision agriculture technology while ensuring sustainability through renewable wind energy harvesting.

**Keywords:** Precision agriculture, wind-adaptive spraying, renewable energy harvesting, ESP32 automation, coastal farming, pesticide drift mitigation, smallholder technology.

## I. INTRODUCTION

Agriculture remains the backbone of India's rural economy, employing over 60% of small-scale farmers concentrated in coastal regions like Tamil Nadu, where particular crops (vegetable crops, root crops, green leaves, green vegetables) cultivation supports millions. Agriculture heavily depends on pesticide spraying for crop protection. Traditional manual and motorized sprayers operate with fixed spray direction and constant pressure, regardless of environmental conditions. Wind influence in open agricultural fields causes spray drift, leading to inefficient chemical usage and ecological damage. Recent developments in precision agriculture emphasize sensor-based adaptive systems to improve spraying efficiency. However, most existing systems rely on expensive GPS-guided platforms or advanced automation techniques, making them unsuitable for small-scale farmers.

This research introduces a wind-aware robotic spraying system that:

Monitors wind speed and direction, Adjusts spray nozzle activation accordingly, Controls spray pressure based

on wind intensity, Operates on a mobile robotic platform, Utilizes wind power as an auxiliary energy source

The system is designed as a low-cost, scalable prototype suitable for academic and practical agricultural applications. Traditional knapsack sprayers waste 20-40% of pesticides due to wind drift, increasing costs and environmental harm.

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## Problem statement

In agricultural fields, especially in coastal and open-land regions, wind significantly affects pesticide spraying operations. Conventional sprayers operate without considering real-time wind conditions, leading to:

Spray drift and loss of chemicals, Uneven crop coverage, Environmental contamination, Increased operational cost, Health hazards to farmers.

There is a need for a cost-effective and intelligent spraying system that adapts spraying direction and intensity based on real-time wind behavior while enabling mobility for field coverage.

## Objectives

90% spray efficiency, 25-40% chemical savings and sustainable energy use.

## Existing System

Conventional agricultural spraying systems include:

1. Manual hand sprayers
2. Tractor-mounted boom sprayers

3. Battery-powered backpack sprayers  
Advanced smart sprayers exist but are: Expensive, Complex, Not suitable for small-scale deployment.

Thus, there is a technological gap between low-cost manual systems and expensive precision agriculture solutions.

**Working principle**

The wind vane operates based on aerodynamic alignment. When wind flows, it exerts force on the tail, causing the vane to rotate. The system stabilizes when the vane aligns with the wind direction.

The angular position of the vane corresponds to a specific wind direction.

**Signal Generation**

The mechanical rotation is converted into an electrical signal using one of the following

**Methods:**

Potentiometer-based sensing (analog output), Magnetic encoder, Optical encoder (high precision systems). In analog systems, the output voltage varies continuously based on the angle of rotation.

**Output Characteristics**

Typical output:

Voltage range: 0V to 5V or 0V to 3.3V

Direction mapping:

1. 0° (North) → Minimum voltage
2. 90° (East) → Mid voltage
3. 180° (South) → Higher voltage
4. 270° (West) → Near maximum voltage

**Interfacing with Microcontrollers**

The sensor can be interfaced with controllers such as:

- Arduino
- ESP32
- STM32

Basic Steps:

1. Connect sensor output to ADC pin
2. Read analog voltage
3. Convert voltage to angle (0°–360°)

4. Map angle to direction (N, NE, E, etc.)

**Communication Interfaces**

Depending on the model, the sensor supports:

Analog output (simple systems),

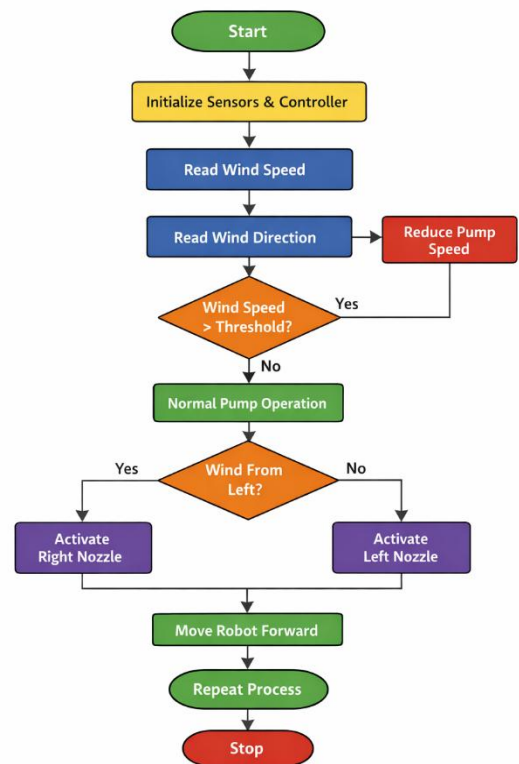
RS485 communication (industrial systems),

Modbus protocol (long-distance, noise-resistant communication)

The Smart Coastal Sprayer operates on the principle of renewable energy utilization and controlled pesticide application. The system integrates a small wind turbine unit that captures coastal wind energy and converts it into electrical energy through a generator. This generated power is stored in a rechargeable battery using a charge controller to ensure safe and efficient charging.

**Materials and methodology**

Prototype wind turbine (auxiliary power), 12V battery storage system, Wind speed sensor (anemometer), Wind direction sensor (wind vane), ESP32 microcontroller, DC spray pump, Dual spray nozzles (Left & Right), Solenoid valves for directional control, Basic wheeled robotic chassis



**Architecture**

The smart coastal sprayer employs a three-layer modular architecture—Sensing, Processing, and Actuation—

designed for real-time wind adaptation and self-charging, ensuring >90% spray efficiency in 5-25 km/h coastal winds.

### System components and specification

**Key Functional Features:** Real-time wind monitoring, Direction-based nozzle activation, Pump speed modulation based on wind speed, Robotic mobility for field coverage, Energy support through wind turbine prototype. The controller ensures spraying is performed opposite to wind direction to reduce chemical drift.

### Wind Turbine and Power Management System

The proposed system incorporates a prototype-scale wind turbine as an auxiliary renewable energy source. The turbine converts kinetic energy from wind into electrical energy through a permanent magnet generator mechanism. Since wind conditions in coastal agricultural regions are generally consistent, the turbine assists in reducing dependency on external charging.

The generated AC voltage from the turbine is rectified and regulated using a power management circuit consisting of: Bridge rectifier, Voltage regulator, Charge controller. The regulated DC output is used to charge a 12V rechargeable battery. The battery acts as the primary power buffer, ensuring continuous system operation even during low wind conditions.

The power management module distributes regulated voltage to: ESP32 controller, Sensors, Motor driver, Pump driver, Solenoid valves. This subsystem ensures voltage stability, prevents overcharging, and maintains safe operation of electronic components.

### Energy Storing Device

In electrochemical cells, the chemical energy is converted into electrical energy. The cell potential is related to free energy change ( $\Delta G$ ). In an electrochemical cell, the system does work by transferring electrical energy through an electric circuit. Thus  $\Delta G$  for a reaction is a measure of the maximum useful work, that can be obtained from a chemical reaction.

i.e.,  $\Delta G = \text{maximum work}$

But we know that maximum work  $= nFE$

When a cell operates, work is done on the surroundings (flow of electricity).

$\Delta G = -nFE$  (or)  $\Delta G < 0$

Decrease in free energy is indicated by (-)vesign. One of the main uses of the galvanic cells is the generation of portable electrical energy. These cells are known as batteries.

### Definition

A battery is an arrangement of several electrochemical cells connected in series, that can be used as a source of direct electric current. Thus,

A cell : Contains only one anode and cathode.

A Battery : Contains several anodes and cathodes.

**Requirements of a battery:** A useful battery should fulfill the following requirements. It should be light and compact for easy transport. It should have long life both when it is being used and when it is not used. The voltage of the battery should not vary appreciably during its use.

### Lithium Battery

Lithium battery is a solid state battery because instead of liquid or a paste electrolyte, solid electrolyte is used. **Construction:** The lithium battery consists of a lithium anode and a  $TiS_2$  cathode. A solid electrolyte, generally a polymer, is packed in between the electrodes. The electrolyte (polymer) permits the passage of ions but not that of electrons.

### Wind Speed Sensor

The wind speed sensor continuously measures real-time wind velocity in meters per second (m/s). The anemometer produces pulse outputs proportional to rotational speed caused by airflow. The sensor output is interfaced with the ESP32 microcontroller, where pulse frequency is converted into wind speed values using calibration constants.

**Functional Role in System:** When wind speed is below threshold  $\rightarrow$  Normal spray pressure is maintained. When wind speed exceeds threshold  $\rightarrow$  Pump speed is reduced using PWM control. By reducing pump pressure at high wind speeds, the droplet size increases slightly, reducing spray drift and chemical dispersion beyond the target crop area. This adaptive control improves: Chemical efficiency, Environmental protection, Crop coverage accuracy.

### Wind Direction Sensor

The wind direction sensor determines the angular direction of wind flow relative to the robot's orientation. The wind vane produces an analog voltage output corresponding to specific angular positions ( $0^\circ$ – $360^\circ$ ). The ESP32 reads this

analog value and determines wind direction categories such as: Wind from left, Wind from right, Wind from front, Wind from rear.

**Control Strategy:** If wind is detected from the left side: Left nozzle is deactivated, Right nozzle is activated. If wind is detected from the right side: Right nozzle is deactivated, Left nozzle is activated. This ensures spraying always occurs opposite to wind direction, minimizing chemical drift and maximizing deposition on crops. This feature represents the primary novelty of the system.

### Sensor Description

A tail (fin) that captures wind force, A rotating shaft mechanism, An internal sensing unit (potentiometer or encoder), A base enclosure for mounting and protection. The sensor shown is designed for outdoor use, with a robust structure and weather-resistant materials.

### ESP32 Microcontroller Unit

The ESP32 serves as the central control and decision-making unit of the system. It integrates sensor acquisition, data processing, and actuator control within a single embedded platform. Explains the features and applications of the ESP32 microcontroller, mainly used in IoT and embedded systems. It highlights that ESP32 supports Wi-Fi and Bluetooth, making it suitable for smart home automation, environmental monitoring, and industrial applications.

### ESP32 Application

ESP32 is widely used in IoT-based applications for collecting, processing, and transmitting data from sensors. It connects with various IoT sensors to measure environmental parameters and sends the data through communication modules like Wi-Fi or Bluetooth. The processed data can be stored internally or displayed using devices like ESP32 helps in real-time data visualization and monitoring. It supports communication with cloud platforms and other devices, making it suitable for smart home systems, industrial monitoring, and automation. The system can also show status information such as connectivity, processing activity, and sensor outputs on display modules.

### Spray Control System

The spray control subsystem consists of: 12V DC water pump, PWM pump driver (MOSFET-based), Two solenoid valves, Two spray nozzles.

### L298 Motor Driver

L298 46V, 2A Stepper Motor / Dual DC Motor Driver module can drive bipolar stepper motor or Two DC motors at the same time. Each L298 has two H-Bridges. Each H-Bridge can supply 2Amp. current. L298 has heat sink for better heat dissipation and flyback diodes for protection from back EMF (Electromotive Force). For higher current rating these H-Bridges can be connected in parallel.

### Control Logic

**Direction Control:** Forward: IN1 HIGH, IN2 LOW. Reverse: IN1 LOW, IN2 HIGH. Stop: IN1 & IN2 same (both LOW or both HIGH). **Speed Control:** Apply `analogWrite(PWM_Pin, 0-255)` to ENA/ENB. ENA/ENB Connected To Arduino PWM Pins For Speed Control.

### Wind Speed Adaptation Performance

The wind speed sensor successfully measured real-time wind velocity and transmitted data to the ESP32 controller. The response time between wind detection and pump speed adjustment was approximately 1–2 seconds, which is suitable for agricultural spraying operations. This demonstrates effective dynamic pressure control.

### Wind Direction-Based Nozzle Switching

The wind vane sensor successfully detected directional variations. **Functional Validation:** When wind flowed from the left side → Right nozzle activated. When wind flowed from the right side → Left nozzle activated. No simultaneous dual-side spraying occurred during directional wind presence. This ensured that spray was always projected opposite to wind direction, reducing spray drift significantly. Directional switching response time was observed to be less than 2 seconds, indicating efficient real-time control.

### Spray Drift Reduction

Compared to a conventional fixed-direction sprayer: Reduced visible drift during moderate wind conditions, Improved droplet deposition on crop surface, Decreased chemical wastage, Qualitative analysis showed better directional targeting and minimized off-target spray.

### :Relationship Between Wind Speed and Battery Charging Efficiency

X-Axis: Wind Speed (m/s)

Y-Axis: Battery Charging Power (W)

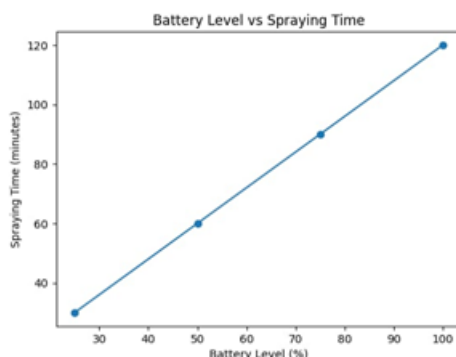
Battery level(%)	Spraying time (mins)
100	120 min
75	90 min
50	60 min
25	30 min

Wind speed(m/s)	Charging power(W)
2	5
4	15
6	35
8	60

When the **wind speed increases, the wind turbine generates more power**, which results in higher battery charging.

**Battery Level vs Spraying Time**

X-Axis: Battery Capacity (%)  
 Y-Axis: Spraying Time (minutes)



This graph indicates that the **spraying time decreases as the battery level decreases**.

**Crop coverage vs Time Calculation**

Crop coverage (area)=speed × spray width × Time

Where:

Speed = Sprayer moving speed (m/s or km/h)

Spray Width = Nozzle spray width (m)

Time = Spraying time

**Example Values**

Sprayer speed = 1 m/s

Spray width = 2 m

Time = 10 minutes

Step 1: Convert time to seconds

10 min = 600 seconds

**Area Covered Calculation**

Area=1 × 2 × 600

Area=1200 m<sup>2</sup>

**Convert to Acre**

1 acre = 4047 m<sup>2</sup>

Acre=1200/4047

Acre ≈0.30 acre

So,

10 minutes → 0.30 acre coverage

The smart coastal sprayer can cover **approximately 0.30 acre in 10 minutes**, and **nearly 1 acre within 30–35 minutes**, depending on spraying speed and nozzle width.

**Applications**

**Weather Monitoring Systems:**Used in meteorological stations for real-time wind direction tracking.  
**Agriculture:**Helps in precision farming by analyzing wind patterns for irrigation and pesticide spraying.  
**Renewable Energy:** Used in wind turbines to optimize blade orientation and improve efficiency.  
**Environmental Monitoring:** Assists in tracking air pollution dispersion and environmental changes.  
**IoT-Based Systems:** Integrated into smart monitoring systems for remote data collection and cloud analysis.

**II. CONCLUSION**

The proposed Wind-Assisted Smart Coastal Sprayer successfully integrates renewable wind energy with intelligent

spray control technology to enhance agricultural efficiency in coastal regions. The system effectively utilizes a small wind turbine and MPPT charge controller to generate and store electrical energy in a lithium battery pack, ensuring sustainable and cost-effective operation. The integration of wind sensors and the ESP32 microcontroller enables real-time monitoring of wind speed and direction, allowing adaptive spray control to reduce pesticide drift and improve coverage uniformity. This research presented the design and implementation of a wind-powered, direction-adaptive robotic agricultural spraying system. The system integrates wind speed and wind direction sensing with real-time control logic to dynamically adjust spray pressure and nozzle activation.

### Advantages

Simple mechanical design, Reliable operation, Low power consumption, Easy integration with embedded systems, Suitable for harsh outdoor environments, Suitable for coastal areas with high wind availability, Eco-friendly and reduces carbon footprint, Automated spraying improves uniform crop coverage, Reduces manual labor and farmer effort, cost-effective for small-scale farmers.

### Disadvantages

Suitable for particular row crops (vegetable crops, root crops, green leafy, green vegetables), Dependent on wind availability – Low or inconsistent wind reduces charging efficiency, Corrosion risk in coastal areas – Salt air can damage turbine, electronics, and metal parts, High initial cost – Wind turbine, sensors, MPPT controller, and app integration increase cost, Maintenance required – Turbine blades, sensors, pump, and nozzles need regular servicing, App dependency – Requires smartphone and network connectivity for monitoring, System complexity – Multiple components (ESP32, IMU, wind sensor) increase chances of failure.

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### REFERENCE

- [1] “Design, Development And Analysis of pesticide sprayer” By Dr. H. Erdal Ozkan in May 2015
- [2] “Development And Evaluation Of Automatic sprayer” By Silas O. N, Kakini, And Abu Husseni in January 2015 [5] “Development Of Double Wheel Multi Use Manually Operated sprayer” By Sridhar. H. S, November 2013.
- [3] “Development Of Double Wheel Multi Use Manually Operated sprayer” By Sridhar. H. S, November 2013.
- [4] “Design And Fabrication Of Manually Operated Sprayer With pesticides Sprayer” By M. G. Jadhav, Prof. J. K. Sawale, December 2016
- [5] Laukik P. Raut, Smit B. Jaiswal, Nitin Y. Mohite (2013): Design, development and fabrication of agricultural pesticides, International Journal of Applied Research and Studies (IJARS)
- [6] Monte P. Johnson, Entomology, and Larry D. Swetnam, (2012): Sprayer nozzles selection & calibration, (University of Kentucky college of agriculture).
- [7] A research paper on “Fabrication of Portable Foot Operated Agricultural Fertilizers and Pesticides Spraying Pump” by S R Kulkarni, R V Nyamagoud, Hareesh Naik, Mohan Futane
- [8] A research paper on “Design, development and fabrication of agricultural pesticides sprayer with weeder” by Laukik P. Raut, Smit B. Jaiswal, Nitin Y. Mohite
- [9] R. Joshua, V. Vasu and P. Vincent “Solar Sprayer – An Agriculture Implement”, “International Journal of Sustainable Agriculture 2 (1): 16-19, 2010 ISSN 2079-2107”
- [10] R. D. Fox, R. C. Derksen, “Visual and image system measurement of spray deposits using water-sensitive paper” Applied Engineering in Agriculture Vol. 19(5): 549–552 2003 American Society of Agricultural Engineers ISSN 0883–8542
- [11] A research paper on “Review of Solar Powered Pesticide Sprayer” by Sarvesh Kulkarni, Karan Hasurkar, Ramdas Kumbhar, Amol Gonde, Raut A.S.
- [12] M. A. Miller, B. L. Steward, M. L. Westphalen “Effects of multi-mode four-wheel steering on sprayer machine performance”, American Society of Agricultural Engineers ISSN 0001–2351 A. Taiwo K. Oje, “Development and testing of a swirl chamber nozzle”,

- Journal of Agricultural Engineering and Technology (JAET), Volume 16 (NO. 1) June,2008
- [13] Mohammed Umair Ahmad ,Shrijit Haridas Borkar , S.D. Ghatole “Review Manually Operated Multi-Nozzle Pesticide Sprayer Pump”
- [14] S.S.Patil, G.P.Ikile, S.R.Jangate, A.M.Patil, D.K.Nalawade “Pedal operated multipoint pesticide sprayer, Ergonomics, Pressure and Nozzle”
- [15] Vipul Jhod, Akshay Jumle, Saurabh Apte, Ninad Borkar “Self poweredpestro sprayer”
- [16] S. L.Kolhe, N B. Gajbhiye, V. B. Deshmukh, ”Eco-friendly Mechanically Operated Multipurpose Spray Pump” International Journal of Research in Advent Technology, Vol.2, No.2, February 2014.
- [17] Sandeep H. Poratkar, Dhanraj R. Raut ”Development of Multinozzle Pesticide Sprayer Pump”, International Journal of Modern Engineering Research (IJMER), Vol.3, Issue.2, pp 864-868, April 2013.
- [18] ShaileshMalonde,ShubhamKathwate,PratikKolhe,RoadneyJacob, NishantIngole, “Design and Development of Multipurpose Pesticides SprayingMachine”, “Journal of Advanced Engineering and Global Tecnolagy”,ISSN:23094893,Volume02,Issue -03,May 2016
- [19] Shivaraja Kumar Pwameswaramurthy, Design and development of wheel and pedal operated sprayer”, IPSJinternational journal of mechanical Engineering (IJME), volume 2, Issue 6, june 2014.
- [20] “Design and Fabrication of Battery spraying machine” By S. T. NangareIn November 2014
- [21] “Development Of Double nozzle Multipurpose sprayer” ByGururaj P. Bhumannavar in February 2015