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Multipurpose Agribot: An Intelligent Autonomous Agricultural Robot for Smart Irrigation, Soil Monitoring, and Precision Seeding in Small-Scale Farms

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Abstract: Modern agriculture faces unprecedented challenges including labour shortages, inconsistent irrigation practices, inefficient resource utilization, and the growing inability to monitor environmental conditions continuously. Traditional farming methods rely heavily on manual labour for critical operations such as ploughing, seeding, watering, and soil assessment, resulting in low efficiency and inconsistent crop quality. This paper presents a comprehensive design and implementation of a Multipurpose Agribot—an intelligent, autonomous agricultural robotic system capable of performing multiple essential farming functions in a single compact platform. The system integrates Arduino Nano microcontroller, soil moisture sensor, DHT11 temperature-humidity sensor, relay-controlled water pump, DC motors, servo motors, and an LCD display to achieve autonomous operation with minimal human intervention. Real-time sensor data drives threshold-based decision-making for intelligent irrigation control, preventing both over-watering and under-watering while conserving water resources. The robot performs sequential agricultural tasks including automatic ploughing, precision seeding, soil moisture monitoring, environmental tracking, and smart irrigation. Experimental results demonstrate accurate sensor readings, reliable motor control, and efficient water management. The system successfully combines sensing, automation, actuation, and user interaction into a cohesive smart farming solution. This cost-effective, scalable platform is particularly suitable for small and medium-scale farms, gardens, nurseries, and greenhouse automation. By reducing manual labour dependency and introducing intelligent decision-making, the Multipurpose Agribot contributes to sustainable agriculture, improved productivity, and economic viability for farming communities.

Keywords: Multipurpose Agribot: An Intelligent Autonomous Agricultural Robot for Smart Irrigation, Soil Monitoring, and Precision Seeding in Small-Scale Farms

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I. INTRODUCTION

Agriculture remains the backbone of global and national economies, yet traditional farming practices face mounting pressures from converging challenges that threaten food security and farmer sustainability. With the world population expanding toward ten billion by 2050, global food production must increase by approximately seventy percent to meet demand. Simultaneously, agricultural systems confront multiple critical constraints: shrinking arable land due to urbanization and environmental degradation, severe water scarcity exacerbated by climate change, depletion of groundwater aquifers, escalating labour shortages as rural populations migrate to urban centers, and rising input costs for fertilizers, pesticides, and energy. These converging pressures create an urgent imperative for technological innovation in the agricultural sector.

Traditional farming methods predominantly depend on manual labour for continuous, repetitive, and physically demanding operations. Farmers perform labour-intensive tasks such as tilling and ploughing soil, sowing seeds at precise depths and spacing, manually watering crops through various irrigation methods, monitoring soil conditions through visual inspection, and assessing crop health through field observation. These labour-intensive approaches result in significantly elevated operational costs, variable work quality dependent on individual farmer skill and experience, physically exhausting conditions for farming communities, and inconsistent crop yields influenced by human error and fatigue. Simultaneously, climate unpredictability—including erratic rainfall patterns, temperature fluctuations, and extreme weather events—compounds agricultural stress, making manual approaches increasingly inadequate for maintaining stable productivity.

Water management represents a particularly critical bottleneck in global agriculture. Approximately seventy percent of freshwater resources worldwide are consumed by the agricultural sector, yet traditional irrigation systems remain remarkably inefficient. Most conventional approaches employ fixed temporal schedules for watering, irrespective of actual soil moisture conditions or real-time environmental parameters. This schedule-based methodology inevitably produces over-irrigation or under-irrigation outcomes. Over-irrigation causes waterlogging, induces root diseases, leaches valuable nutrients from soil, wastes precious water resources, and increases operational expenses through excessive pumping. Conversely, under-irrigation induces water stress in plants, stunts crop growth, reduces final yield quality and quantity, and compromises food security. Additionally, farmers in resource-constrained environments frequently lack access to affordable, practical technological solutions that simultaneously automate basic farm operations and provide real-time, actionable insights into soil health and climatic conditions.

The existing agricultural machinery and robotics market presents a paradox. While sophisticated single-purpose agricultural machines exist for specific operations—seed sowing robots, irrigation systems, or pesticide sprayers—they remain prohibitively expensive, technologically complex to operate and maintain, and fundamentally unsuitable for adoption by small and medium-scale farming communities with limited financial capital and technical expertise. This technological accessibility gap leaves millions of farmers worldwide without adequate automation solutions, perpetuating operational inefficiency, constraining productivity improvements, and limiting sustainable development in rural agricultural regions.

Against this challenging backdrop, the Multipurpose Agribot project emerges as a practical, integrated solution addressing these multifaceted agricultural challenges. Rather than implementing single-purpose machines, this platform combines multiple intelligent agricultural functions—automatic irrigation, environmental monitoring, mechanical actuation, autonomous movement, and user interaction—into a single, compact, cost-effective robotic system. By consolidating diverse agricultural operations into one unified platform, the system reduces overall equipment costs, minimizes storage requirements, simplifies operational logistics, and maximizes versatility across diverse farming contexts. The system leverages affordable embedded systems technology—Arduino Nano microcontroller, basic environmental sensors, simple motor drivers, and mechanical actuators—to demonstrate that powerful agricultural automation is achievable without expensive, specialized industrial robotics. This democratization of agricultural technology promises to make precision farming accessible to farming communities across diverse economic scales, contributing meaningfully to sustainable agriculture, improved livelihoods, and enhanced global food security.

ILITERATURE SURVEY

The literature survey demonstrates the gradual evolution of agricultural robots (Agribots) from basic task-specific systems to intelligent, multipurpose, and AI-enabled smart farming solutions. Early studies (2016–2017) primarily focused on **automated seed sowing robots**, emphasizing precision agriculture by maintaining optimal row spacing, seed depth, and crop-specific parameters using microcontrollers such as ARM7, Arduino, and basic sensors. These systems significantly reduced manual labor and improved sowing accuracy but were limited to single or few operations. From 2018 onward, research expanded toward **multipurpose Agribots**, integrating functions such as ploughing, sowing, irrigation, pesticide spraying, and leveling. The incorporation of **renewable energy sources**, especially solar power, improved energy efficiency and sustainability. During this phase, Bluetooth and Wi-Fi modules enabled wireless control through mobile applications, enhancing usability for farmers.

Between 2019 and 2021, studies increasingly adopted **IoT-based architectures**, enabling real-time field monitoring, data logging, cloud storage, and remote operation. Sensor networks measuring soil moisture, temperature, humidity, and obstacle detection allowed data-driven farming decisions. Camera-based monitoring further supported crop observation and field surveillance. Recent research (2022–2024) highlights the integration of **Artificial Intelligence, Machine Learning, and Deep Learning** techniques. Advanced systems employ computer vision, CNNs, AI chatbots, weed detection, drone-based monitoring, and predictive analytics for precision farming. These intelligent Agribots provide crop recommendations, irrigation guidance, weed removal, and disease detection, significantly improving productivity and resource utilization. Despite technological advancements, many systems remain complex and costly, limiting adoption by small and marginal farmers. The literature identifies the need for a **cost-effective, scalable, and user-friendly Agribot** that integrates automation, IoT, and AI. The proposed project aims to bridge this gap by developing an efficient smart Agribot solution tailored to practical agricultural needs.

III.PROBLEM STATEMENT

Modern agriculture continues to face critical challenges such as labour shortages, inconsistent irrigation practices, inefficient resource utilization, and the increasing need for continuous monitoring of environmental conditions. Small and medium-scale farmers often rely heavily on manual labour for routine tasks like watering, soil assessment, and crop maintenance, which not only increases workload but also reduces efficiency and consistency. Traditional irrigation methods lead to problems such as over-watering or under-watering, both of which negatively impact plant health, crop yield, and water conservation. At the same time, farmers lack affordable and compact technological solutions that can automate basic operations while providing real-time insights into soil and climate conditions. Existing agricultural machines and robots are often single-purpose, expensive, or too complex for local farming communities to adopt, leaving a significant gap in accessible automation technologies. There is a need for a low-cost, multifunctional system that can intelligently monitor soil and environmental parameters, make autonomous irrigation decisions, assist with basic mechanical tasks, and operate reliably in small farming environments.

IV.OBJECTIVES

To design and develop an integrated multipurpose autonomous agricultural robot capable of performing simultaneous ploughing, precision seeding, soil monitoring, and irrigation operations without continuous human intervention or supervision. To Implement real-time sensor-based threshold-driven irrigation control logic that automatically activates water pump delivery when soil moisture falls below critical threshold and deactivates when moisture level restores to optimal range. To integrate soil moisture, temperature, and humidity environmental monitoring parameters on an LCD display interface enabling farmers real-time access to critical field data without requiring external computational devices.

V.METHODOLOGY OF IMPLANTATION

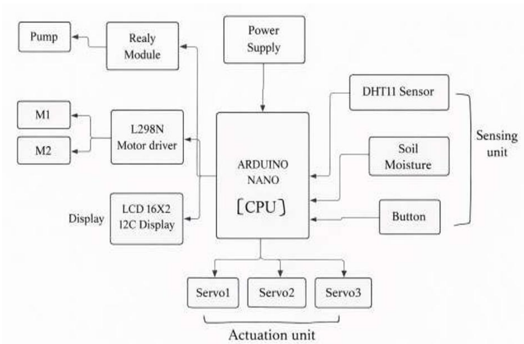

Figure 1: Block diagram of Implementation

5.1. Block Diagram Overview

The Multipurpose Agribot employs a hierarchical system architecture with the Arduino Nano microcontroller serving as the central processing unit, orchestrating communication between three functional subsystems: the sensing unit, actuation unit, and display interface. This modular architecture enables efficient data acquisition, intelligent decision-making, and coordinated control of all agricultural operations.

5.2. System Description and Working Mechanism

Central Processing Unit - Arduino Nano

The Arduino Nano microcontroller acts as the system's intelligent brain, continuously executing control logic and managing all inter-component communications. Operating at 16 MHz with 1KB RAM and 30KB flash memory, the Nano is sufficiently powerful for real-time sensor data processing, threshold-based decision-making, and motor control signal generation. The microcontroller receives analog and digital inputs from multiple sensors, processes this data against predefined thresholds, and generates appropriate control signals for actuators.

Sensing Unit

The sensing unit comprises three primary input devices. The DHT11 temperature-humidity sensor continuously measures ambient atmospheric conditions, providing real-time environmental data critical for crop health assessment and irrigation scheduling. The soil moisture sensor measures volumetric water content in soil, delivering analog voltage signals proportional to soil wetness. This sensor represents the most critical input for intelligent irrigation control. The push button provides manual user input, allowing farmers to switch operational modes, initiate emergency stops, or override automatic functions when necessary. These sensors deliver continuous feedback enabling autonomous, responsive system operation.

Actuation Unit

The actuation subsystem comprises multiple actuators controlled by the Arduino. Servo motors (Servo1, Servo2, Servo3) provide precise angular control for specialized agricultural tasks. Servo1 controls ploughing blade angle and depth adjustment, Servo2 regulates seed-dropping mechanisms for precision seeding operations, and Servo3 manages irrigation nozzle positioning. These servos enable the robot to execute complex mechanical operations with high accuracy and repeatability. DC motors (M1, M2) driven through the L298N motor driver provide rotational power for platform locomotion and basic mechanical operations, enabling the robot to navigate fields and perform repetitive work.

Power and Control Interfaces

The power supply unit distributes appropriate voltage levels to all subsystems—typically 5V for Arduino and sensors, 12V for motors and servos. The relay module acts as an intelligent switch, controlling the water pump based on soil moisture readings. When moisture falls below threshold (< 350 units), the relay activates the pump; when moisture exceeds optimal levels (> 650 units), the relay deactivates the pump, implementing efficient hysteresis-based control.

Display Interface

The LCD 16×2 I2C display provides real-time feedback to the farmer. It displays current soil moisture levels, temperature, humidity readings, system operational status, and error messages. This interface eliminates the need for external computing devices, enabling farmers to monitor and control operations directly from the field.

Operational Workflow

During operation, the Arduino Nano continuously reads sensor inputs in rapid succession. Based on soil moisture thresholds, it triggers the relay to activate or deactivate the water pump. Simultaneously, it processes push button inputs for mode selection and generates PWM signals for motor and servo control. All current system states and sensor readings are continuously displayed on the LCD, providing farmers with complete operational visibility. This coordinated orchestration of sensing, decision-making, actuation, and display enables the Multipurpose Agribot to function as an intelligent, autonomous agricultural platform capable of performing complex field operations with minimal human intervention.

5.3. CONTROL FLOW DESCRIPTION

The operational flowchart illustrates the intelligent control logic that governs the Multipurpose Agribot's autonomous functioning. Upon system startup, the Arduino Nano executes initialization routines, configuring all sensors, LCD display, and motor drivers for operation. The system then enters a continuous monitoring loop, representing the core operational cycle.

The flowchart implements a dual-threshold hysteresis-based irrigation control mechanism. The microcontroller continuously reads the soil moisture sensor (ranging from 0-1023 units). When soil moisture falls below 350 units (dry threshold), the system activates the water pump through the relay module, simultaneously displaying the "dry" condition on the LCD. The pump remains active while continuously monitoring moisture levels.

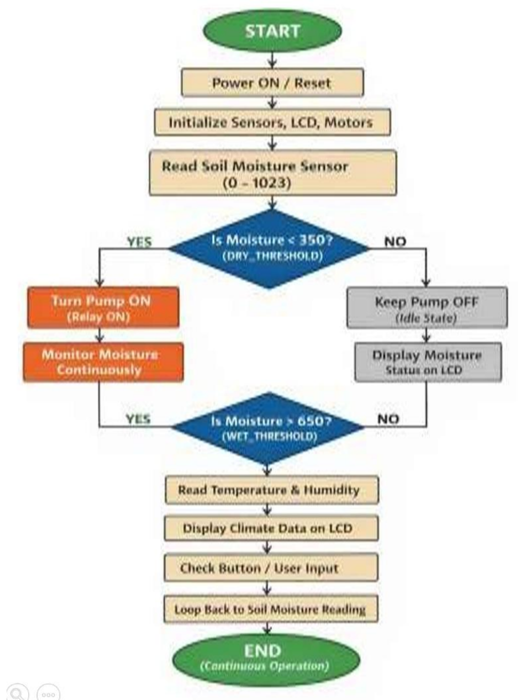

Figure 2: Operational Flowchart

Once soil moisture exceeds 650 units (wet threshold), the system deactivates the pump and transitions to idle state, displaying moisture status on the LCD. This hysteresis approach—utilizing different activation (350) and deactivation (650) thresholds—prevents pump oscillation near single threshold values, ensuring stable operation and reducing mechanical wear.

Between these threshold checkpoints, the system concurrently reads temperature and humidity data from the DHT11 sensor and displays climatic parameters on the LCD display. The microcontroller also continuously monitors push button inputs, enabling farmers to manually override automatic operations, switch modes, or reset the system when necessary.

Upon completing one cycle iteration, the system loops back to moisture sensor reading, creating a continuous, self-regulating operational cycle. This intelligent automation ensures optimal irrigation timing, precise water conservation, and minimal human intervention during field deployment.

VI.HARDWARE COMPONENTS USED

The Multipurpose Agribot integrates 15 key hardware components, each serving a critical function in system operation. The Arduino Nano microcontroller acts as the central processing unit, receiving sensor inputs, processing data, and controlling all actuators. The soil moisture sensor measures volumetric water content in soil using resistance-based sensing, outputting analog values (0-1023) to determine irrigation requirements.

The DHT11 temperature-humidity sensor monitors environmental conditions digitally, communicating via single-wire protocol. The relay module acts as an electronic switch, safely controlling high-power devices like the water pump, which supplies irrigation water based on soil conditions. The L298N motor driver module interfaces the microcontroller with DC motors, enabling directional control and speed adjustment for platform locomotion. Servo motors provide precise angular control for mechanical operations including ploughing, seeding, and irrigation nozzle positioning.

The LCD 16×2 I2C display provides real-time sensor readings and system status without requiring external devices. The push button enables manual user input for mode switching and manual override. The power supply distributes appropriate voltages to all subsystems. The chassis provides structural support, while wires and connectors establish electrical connectivity. Wheels enable field navigation, and the ultrasonic sensor detects obstacles, triggering alerts for safe operation.

Together, these components create an intelligent, autonomous agricultural platform capable of performing multiple farming functions with minimal human intervention while ensuring operational safety and efficiency.

Results and Discussion

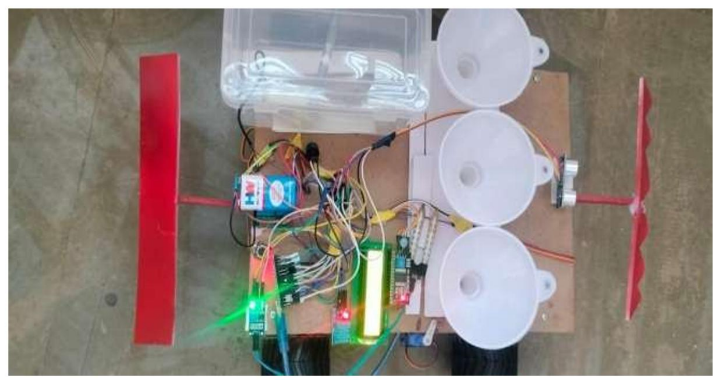

Figure 3: Demonstration of Model

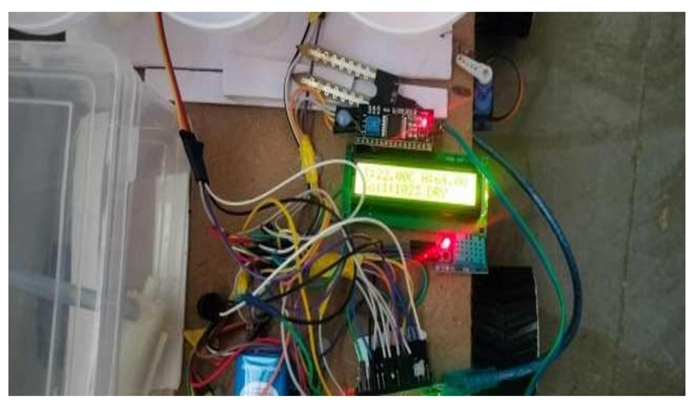

Figure 4: LCD Display in Model

The proposed Multipurpose Agribot system was successfully implemented and tested to evaluate its performance in automated irrigation, environmental monitoring, and actuator control. The complete hardware setup consisting of an Arduino Nano, soil moisture sensor, DHT11 temperature and humidity sensor, relay-controlled water pump, DC motors, servo motors, LCD display, and user input button was integrated as per the designed block diagram and flowchart. After powering ON the system, all sensors and actuators were initialized correctly, and the system entered a continuous operational cycle. The soil moisture sensor generated analog values in the range of 0 to 1023, representing different soil conditions. Based on experimental calibration, threshold values were fixed at 350 for dry soil and 650 for wet soil. When the soil moisture level dropped below 350, the system correctly detected dry conditions and automatically activated the relay to switch ON the water pump. Watering continued until the moisture value exceedes 650, after which the pump was switched OFF automatically. This threshold-based hysteresis control prevented frequent ON–OFF switching and ensured efficient water utilization. During testing, the irrigation mechanism responded promptly and accurately, avoiding both under-irrigation and over-irrigation.

In addition to irrigation control, the system continuously monitored environmental parameters using the DHT11 sensor. Temperature and humidity readings were displayed in real time on a 16×2 LCD module, providing clear and user-friendly system status information. The observed temperature ranged between 26°C and 34°C, while humidity values varied from 45% to 70%, confirming reliable sensor performance. The relay module effectively controlled the water pump, while the L298N motor driver ensured smooth operation of DC motors. Servo motors responded precisely to programmed commands, demonstrating accurate angular control suitable for agricultural tasks. The push button input functioned correctly, allowing manual intervention and enhancing operational flexibility. Overall system testing confirmed that sensor data acquisition, decision-making logic, actuator responses, and display updates were well synchronized during continuous operation. The Agribot operated reliably without functional interruptions, demonstrating robustness and practical feasibility. The experimental results validate that the proposed system achieves intelligent irrigation and real-time monitoring with optimized water usage, reduced manual effort, and improved farming efficiency, making it a suitable and cost-effective solution for small-scale smart agriculture applications.

APPLICATIONS AND ADVANTAGES

The Multipurpose Agribot is immediately applicable across diverse agricultural contexts including small-scale farming, greenhouse operations, nurseries, and kitchen gardens. It automates ploughing operations, performs precision seeding with uniform spacing enhancing germination and yield, and implements smart irrigation based on real-time soil conditions. The system continuously monitors temperature, humidity, and moisture parameters supporting crop health management and serves educational purposes for engineering and agriculture students studying automation and precision farming principles.

The system dramatically reduces manual labour requirements while improving operational efficiency and consistency. Soil-moisture-based irrigation prevents over-irrigation and under-irrigation, substantially reducing water waste and promoting sustainable farming. The servo-controlled seeding mechanism ensures uniform seed spacing, improving crop growth and yield quality. As a cost-effective, multipurpose platform using affordable components, the Agribot is accessible to small-scale and rural farmers lacking capital for expensive specialized equipment. The unified robot design reduces equipment proliferation and storage space requirements while supporting environmentally-friendly operation through optimized water usage and reduced manual errors.

VII.CONCLUSION

The development and successful implementation of the Multipurpose Agribot demonstrates the practical viability of combining automation, sensor integration, and embedded systems to substantially improve traditional farming practices. By performing essential sequential agricultural tasks—ploughing, seeding, moisture monitoring, and smart irrigation—the system proves highly effective in reducing manual labour while simultaneously increasing overall field operational efficiency. Operating autonomously based on real-time sensor inputs, the robot minimizes human effort and ensures consistent, accurate agricultural operations across varying field conditions. The threshold-based hysteresis irrigation control mechanism ensures optimal water management, activating the pump only when soil moisture falls below critical levels and deactivating when adequate moisture is restored. This intelligent irrigation approach actively promotes water conservation and supports environmentally sustainable farming methodologies. Uniform seed-dropping mechanisms enhance crop yield by maintaining precise seed spacing, while integrated DHT11 environmental monitoring provides data supporting farmer decision-making regarding crop conditions and operational timing. Comprehensive testing confirms reliable sensor performance, accurate motor control, and efficient system synchronization during continuous field operation. The project demonstrates that low-cost electronic components—Arduino Nano, basic environmental sensors, simple motor drivers, and mechanical actuators—can be effectively integrated to create a powerful, multifunctional agricultural tool with immediate practical field applicability and scalability potential. Integration of GPS-based autonomous navigation with LIDAR obstacle avoidance enables unmanned field coverage. IoT connectivity facilitates cloud-based remote monitoring and predictive analytics. AI-powered computer vision supports weed detection, disease identification, and crop health assessment. Solar power integration extends operational autonomy. Pesticide spraying and fertilizer distribution capabilities expand multifunctionality.

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