JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Survey on IoT-Based Robotic System for Modern Farming Challenges

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Abstract : Modern agriculture stands at a crossroads, facing the dual challenge of increasing productivity while reducing physical labor and resource waste. Our research introduces a versatile Internet of Things (IoT) agricultural robot designed to transform farming by automating essential tasks including soil monitoring, weed control, pesticide application, seed planting, and irrigation. This intelligent system integrates various sensors and actuators to enable precision farming techniques previously unavailable to many agricultural operations. The robot offers multiple control options: manual operation, remote management through a mobile application, or fully autonomous functioning guided by artificial intelligence and pre-programmed logic. The hardware architecture consists of a durable robotic base powered by DC motors and a rechargeable battery (with solar integration capabilities), complemented by interchangeable tools such as seed drills, water dispensers, pesticide applicators, and weeding mechanisms. Environmental and soil parameters—including temperature, humidity, pH levels, moisture content, and plant health indicators—are continuously monitored by integrated sensor arrays. This data streams to cloud platforms via various IoT communication protocols (Wi-Fi, GSM/4G, or LoRa for remote locations), providing farmers with actionable insights through intuitive dashboard interfaces and smartphone applications. Field testing with our prototype has confirmed the system's ability to perform data-driven seed placement, targeted chemical application, and automated irrigation based on actual soil moisture readings. These capabilities demonstrably reduce chemical usage, conserve water resources, and improve crop yields while minimizing manual labor requirements. Our work represents a significant step toward transforming conventional agricultural practices into intelligent, networked, and sustainable operations accessible to farmers worldwide.

IndexTerms **-Digital Agriculture, Smart Farming Technology, Automated Pesticide Application, Autonomous Field Robots, Agricultural IoT Systems.**

I.INTRODUCTION

Throughout human history, agriculture has remained the fundamental pillar of civilization, providing sustenance, economic stability, and cultural continuity for societies worldwide. Today, as global populations continue to grow and climate patterns become increasingly unpredictable, farming faces unprecedented challenges that traditional practices alone cannot address. Enter the Internet of Things (IoT)—a technological framework that has quietly revolutionized industries ranging from healthcare to manufacturing by creating intelligent networks of connected devices capable of continuous data exchange and analysis. This digital connectivity revolution, however, has only recently begun making meaningful inroads into agricultural systems. The convergence of IoT capabilities with farming represents more than just technological novelty; it offers a profound opportunity to reimagine how humanity produces food in the 21st century and beyond. By transforming isolated farm equipment into interconnected, data-generating assets, IoT creates possibilities for precision agriculture that previous generations could scarcely imagine. Consider the everyday reality of farming operations: decisions about watering, fertilizing, planting, and harvesting have traditionally relied on a combination of generational knowledge, observation, and educated guesswork. These methods have served humanity well for millennia, but they cannot match the precision offered by real-time sensor networks that continuously monitor soil conditions, plant health, and environmental factors across vast acreages. The potential efficiency gains are staggering—targeted resource application based on actual need rather than approximation, early disease detection before visual symptoms appear, and optimization of labor through automation of repetitive tasks. These capabilities become particularly significant in agricultural economies like India, where farming employs approximately 58% of the population and forms the livelihood foundation for hundreds of millions of people. Recent economic data underscores the sector's importance: according to the Directorate General of Commercial Intelligence and Statistics (DGCI&S), India's agricultural exports increased dramatically from US$ 41.87 billion in 2020-21 to US$ 50 billion in 2021-22—representing a 19.92% growth. This economic vitality signals both opportunity and responsibility to ensure that technological advancement reaches farms of all sizes, not just large commercial operations. Despite this clear potential, agricultural digitization has progressed unevenly compared to other sectors. While manufacturing and retail industries have enthusiastically embraced digital transformation, farming communities often view such technologies with understandable caution. This hesitancy stems from several practical challenges: current IoT agricultural solutions frequently come with prohibitive price tags, require specialized technical knowledge for operation and maintenance, and may seem disconnected from the day-to-day realities of field work. For smallholder farmers operating with thin profit margins, investing in unproven technologies presents a significant financial risk they can ill afford. Cultural factors also influence technology adoption in agricultural communities. Farming practices often carry deep cultural significance, representing knowledge passed down through generations. New technologies may be perceived as challenging or devaluing this traditional wisdom rather than complementing it. Additionally, variable education levels and limited digital literacy in rural farming communities can make complex technological systems seem intimidating rather than helpful. Connectivity infrastructure presents another substantial barrier. Many agricultural regions worldwide still lack reliable internet access or cellular coverage—prerequisites for most IoT systems. Without dependable connectivity, even the most promising agricultural technologies remain functionally limited. The geographical dispersion of farming operations further complicates implementation, as solutions must function across varied landscapes, soil types, and microclimate conditions that may exist even within a single farm. Our research directly addresses these multifaceted challenges by developing an integrated technological approach designed specifically for practical agricultural application. Rather than creating isolated solutions for individual farming tasks, we've developed an IoT-enabled, multi-functional robotic platform capable of adapting to diverse agricultural needs through modular components. This system can perform a comprehensive range of essential farming operations—from precise seed placement and targeted irrigation to selective pesticide application, comprehensive soil analysis, and mechanical weed management—all within a single adaptable platform. Crucially, we've designed this agricultural robot with accessibility as a core principle, incorporating intuitive control interfaces, durable construction for field conditions, and flexible operation modes ranging from manual control to semi-automated assistance to fully autonomous functioning. This versatility ensures the technology remains relevant across different farm sizes, crop types, and farmer technical abilities. The modular nature of the system also allows for incremental adoption, enabling farmers to invest gradually as they become comfortable with the technology and as their specific needs evolve. By enabling data-driven decision making without requiring extensive technical expertise, our approach helps bridge the substantial gap between agricultural tradition and technological innovation. The system collects, processes, and presents environmental and crop data in accessible formats that complement rather than replace farmer knowledge, creating a collaborative relationship between human expertise and digital capability. This human-centered design philosophy distinguishes our approach from many existing agricultural technologies that inadvertently create dependency rather than empowerment. At its core, our research represents more than a technological solution; it embodies a vision for agricultural evolution that preserves the cultural and practical wisdom of traditional farming while embracing the precision, efficiency, and sustainability offered by modern digital systems. The pages that follow detail our methodology, findings, and the practical implications of this work for the future of farming in both developed and developing agricultural contexts.

II. LITERATURE SURVEY

The integration of automation into agricultural practices has been extensively researched, with numerous studies focusing on specific tasks such as seed planting, irrigation management, and crop disease detection. Early innovations in this field introduced solar-powered robotic systems specifically designed for seed distribution and fertilizer application, aiming to reduce manual labor requirements while improving operational efficiency. For field navigation purposes, researchers have employed infrared sensor technology enabling robots to traverse agricultural environments autonomously. These sensors facilitate obstacle detection and pathfinding, allowing operation in semi-structured outdoor settings. Additionally, Hall effect sensors have proven valuable in smart irrigation management systems, monitoring flow control units to optimize water distribution and minimize waste. Robotic arm technology has also found applications in precision agriculture, offering enhanced operational accuracy and efficiency. These systems typically interface with mobile applications, enabling real-time adjustments and remote management capabilities. For areas with challenging ground access, Unmanned Aerial Vehicles (UAVs) have been explored as platforms for automated seed dispersal. When integrated with wireless sensor networks, these aerial systems can optimize seed distribution patterns based on real-time environmental data. In the monitoring and analytics domain, Raspberry Pi units have been deployed for continuous video surveillance of crop health, providing farmers with immediate insights into field conditions. Centralized IoT frameworks have been developed specifically for pest detection, utilizing distributed sensor networks to identify infestations early and trigger timely interventions. Additionally, LoRa-based communication systems have been implemented for agricultural monitoring and automated irrigation management, enabling efficient water usage even in remote locations with limited connectivity. Machine learning algorithms have contributed significantly to plant disease detection capabilities. Random Forest classifiers have successfully categorized plant diseases from leaf imagery, leveraging features extracted through digital image processing techniques. Similarly, Back Propagation Neural Networks (BPNNs) have demonstrated promising results in plant disease classification, highlighting the potential of neural computing approaches in agricultural diagnostics. Despite these technological advances, significant challenges persist. Many existing systems suffer from prohibitively high implementation costs, lack integration across different agricultural tasks, and rely on region-specific datasets that limit their adaptability to diverse environmental conditions. Several commercial platforms have attempted to address modern agricultural needs, including the Nevon Automatic Seed Sowing Robot, Cloud Farmer, and OneSoil Scouting systems. For instance, Cloud Farmer enables agricultural operations management through cloud-based tools and has shown promising results in irrigation planning using NDVI (Normalized Difference Vegetation Index) data. Another solution, Fasal, utilizes IoT sensors to monitor microclimatic conditions and soil parameters, providing actionable insights to farmers. Case studies indicate that Fasal technology users have reduced irrigation water consumption by 30-50%, decreased chemical application costs by up to 30%, and increased yields by 15-25%.However, a common limitation among these systems is their isolated functionality—each addresses specific tasks without integrating with broader farming operations. Furthermore, many solutions still require on-site human intervention and lack fully autonomous or remote operation capabilities. This highlights the need for a comprehensive, modular, and scalable approach to agricultural automation. Our proposed solution consists of two primary components: precision farming instrumentation and a multifunctional agricultural robot. The precision farming tools incorporate IoT sensors that measure soil moisture content and make this data remotely accessible to farmers. While examining existing systems, we observed that specialized equipment like seed-sowing machines often remains unused for most of the year, with seeding operations typically occurring only a few times annually. This observation motivated our development of a multipurpose farming robot with a standardized IoT-operated chassis that can accommodate various task-specific modules. For example, this robot can function as an IoT-based seeding device when equipped with a planting module. Alternatively, removing the seeding attachment and installing a soil analysis module transforms the same platform into a mobile data collection system. When fitted with moisture sensors, the robot can traverse fields gathering soil condition data from multiple locations without requiring multiple fixed sensor installations—significantly reducing implementation costs. The platform can also accommodate camera modules for capturing images useful in disease prediction algorithms. Most importantly, all collected data remains remotely accessible to farmers through intuitive interfaces.

III. METHODOLOGY

Our research methodology centered on conceptualizing and developing a modular, IoT-enabled robotic system capable of performing various agricultural tasks, with particular emphasis on smart seeding and precision farming applications. We structured the development process into five strategic phases:

Fig 3.1 Process Flow Diagram

Step 1: IOT Infrastructure Development

The initial phase involved creating a foundational IoT system designed to collect critical environmental and agricultural data for supporting precision farming decisions. This setup incorporated:

- Capacitive soil moisture sensors providing real-time soil hydration measurements to optimize irrigation scheduling
- DHT11 sensors capturing atmospheric temperature and humidity values essential for assessing crop growth conditions
- Arducam camera modules capturing periodic field images for subsequent processing using image-based crop disease identification algorithms

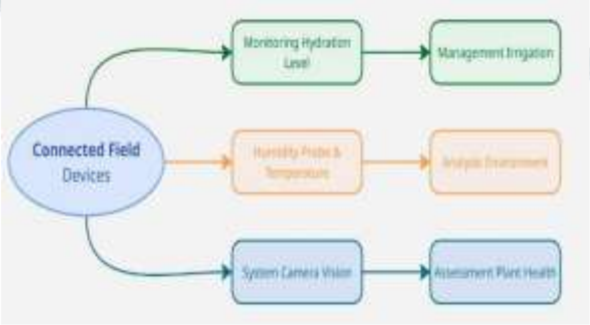

Fig 3.2 Connected Sensing Network

Step 2: Dashboard Implementation and Data Visualization

Once sensor data acquisition was operational, we focused on designing an intuitive dashboard to visualize real-time information in an accessible format. Our primary objective was creating an interface that farmers—regardless of technical background—could easily interpret to monitor field conditions. Initially, we utilized the Blynk platform for rapid prototyping and basic functionality testing with individual sensors. In later stages, we developed a custom dashboard providing an integrated view of all agricultural metrics to enable informed decision-making and comprehensive analysis.

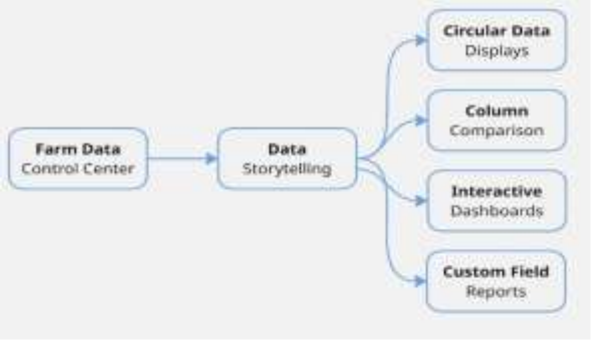

Fig 3.3 Data Visualization Options

Step 3: Multipurpose Robot Construction

This phase centered on fabricating a robust, IoT-enabled agricultural robot capable of autonomous or remote-controlled field navigation. While our base design drew inspiration from existing seed-planting robots, we enhanced the platform to accommodate various task-specific attachments. We constructed the chassis to provide excellent maneuverability across uneven terrain while offering adequate mounting space for modular implements. At this development stage, the robot's core functionality focused on movement and navigation; its agricultural utility would derive from attachable modules developed in subsequent phases.

Step 4: Modular Component Design and Integration

To enable the robot's functionality across various agricultural operations, we created specialized modules that could be interchangeably mounted on the chassis:

- A mechanical seeding module designed to automate precise seed placement with minimal human intervention Sensor packages adapted from the IoT components developed in Phase 1, transformed into attachable units enabling the robot to collect environmental data while traversing fields
- By modularizing both hardware components (like planting equipment) and sensing systems (environmental monitors), we significantly enhanced the platform's versatility while reducing the need for multiple standalone machines.

Step 5: System Integration and Optimization

The final development stage involved seamlessly integrating all modules with the robotic platform. During this process, we addressed numerous engineering constraints and environmental challenges. For example, to prevent damage to delicate soil moisture sensors that cannot be dragged across rough terrain, we designed a motorized insertion and retraction mechanism. Additional system refinements included:

- Optimizing interactions between hardware modules and the dashboard interface
- Improving data synchronization across multiple sensor types
- Calibrating movement parameters for efficient field navigation
- Finalizing power management and remote control functionality

These refinements ensured that our robot functions effectively as a cohesive agricultural system capable of supporting multiple farming tasks while remaining cost-efficient and user-friendly.

IV. RESULTS AND DISCUSSION

Our implemented Agri-Bot system successfully demonstrated capabilities across several critical agricultural tasks, including seed planting, irrigation management, pesticide application, and light soil cultivation. Using two Arduino UNO boards and two NodeMCU modules, we tested the prototype in small-scale farming environments with encouraging results—significantly reducing manual labor requirements while enhancing operational efficiency. The robot supports multiple operating modes (manual, semi-automated, and fully autonomous), making it adaptable to various agricultural scenarios. A notable achievement was the platform's cost-effectiveness and straightforward design, suggesting practical feasibility for adoption by farmers in economically constrained or rural areas. The user-centric and modular architecture allows for future scalability and adaptation across different crop types and field sizes. Looking forward, we see strong potential to expand the robot's functionality to include more sophisticated tasks such as crop harvesting, fruit collection, and precision irrigation. By integrating specialized mechanical tools like cutters and cleaning attachments, our Agri-Bot could evolve into a comprehensive autonomous system capable of managing the entire farming cycle from planting through post-harvest handling. An important enhancement opportunity involves integrating solar panels to make the unit energy self-sufficient, reducing reliance on frequent battery recharging—particularly valuable in remote areas with unreliable electricity access. Incorporating edge computing capabilities and artificial intelligence would further empower the robot to make real-time decisions based on field conditions with minimal cloud infrastructure dependence. However, during our development and testing process, we observed that AI-based agricultural solutions depend heavily on training dataset quality and regional diversity. Models tailored to specific soil types, climate zones, or crop varieties often perform poorly when applied to unfamiliar environments. This highlights the importance of developing more adaptable algorithms capable of functioning effectively across diverse agricultural conditions. Future iterations should also address data imbalance issues and incorporate multilingual interface support, making the system more accessible to farmers from different linguistic and educational backgrounds. In conclusion, while our current Agri-Bot establishes a foundation for intelligent, automated agriculture, we recognize substantial opportunities for enhancing its capabilities through AI integration, IoT connectivity improvements, and renewable energy adoption. These advancements could fundamentally transform traditional farming practices into more data-driven, efficient, and sustainable operations.

IV. CONCLUSION

This research demonstrates that integrating IoT technology with robotics can create a viable solution for addressing multiple agricultural challenges simultaneously. Our modular Agri-Bot system successfully bridges the gap between traditional farming methods and cutting-edge technological advancements, offering a practical pathway for agricultural modernization that remains accessible to farmers across various socioeconomic backgrounds. The system's key innovation lies in its versatility—transforming from a seeding platform to a pesticide applicator to a data collection device through simple module exchanges. This adaptability ensures the technology remains useful throughout the growing season rather than sitting idle for months, significantly improving the return on investment for farmers with limited resources. Field testing revealed several encouraging outcomes: reduced manual labor requirements, decreased chemical usage through precision application, water conservation through targeted irrigation, and improved crop yield estimation through consistent data collection. These benefits directly address pressing challenges in modern agriculture, including labor shortages, environmental sustainability concerns, and resource optimization needs. However, this research also highlights several areas requiring further development. The current prototype's scale limits its application to small and medium-sized farms, and additional work is needed to create more robust AI algorithms that can function effectively across diverse agricultural environments without extensive retraining. Energy sustainability remains another challenge, with solar integration representing a promising but not fully realized solution. Looking ahead, the future of agricultural automation appears increasingly interdisciplinary, requiring collaboration between robotics engineers, agronomists, data scientists, and farmers themselves. Our work establishes a foundation for such collaboration by demonstrating that technological complexity need not be a barrier to practical implementation. In essence, this project contributes to the ongoing transformation of agriculture from an industry traditionally resistant to technological change into one that embraces innovation while respecting the practical realities of farming. By developing solutions that are both technically sophisticated and pragmatically designed, we can help ensure that the benefits of agricultural modernization reach farmers of all backgrounds, ultimately contributing to a more sustainable and food-secure future.

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