Integrating IoT for advancing agriculture: innovations and implications for future surveys

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ABSTRACT

The internet of things (IoT) is revolutionizing agriculture, offering a paradigm shift in how we cultivate crops and manage livestock. By integrating IoT devices such as sensors, drones, and smart machinery into farming practices, agricultural operations gain unprecedented levels of data-driven insights and control. This abstract emphasizes the pivotal role of IoT in agriculture and its far-reaching implications for the future. IoT empowers farmers with real-time information on essential factors like moisture of soil, nutrient levels, weather patterns, and health of crops, helping make accurate decisions while optimizing resources. Through IoT-enabled monitoring and automation, farmers can remotely manage irrigation, pest control, and livestock health, reducing manual labor and minimizing environmental impact. The implications of IoT in agriculture extend beyond individual farms, shaping the future of food production on a global scale. With a burgeoning world population and climate change threatening traditional farming methods, IoT offers solutions for enhancing productivity, sustainability, and resilience in the face of emerging challenges. From precision agriculture to smart supply chains, the revolutionary prospect of IoT in agriculture promises to ensure food security, economic viability, and environmental stewardship for generations to come.

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1. INTRODUCTION

The world's population is expected to grow to 9.8 billion by 2050 and potentially reach 11 billion by the end of 2100. This growth, coupled with factors such as aging populations, urbanization, and shifting consumption patterns, presents significant challenges to the food system. To address these challenges, innovative approaches in agriculture are imperative [1]. The 2030 sustainable development agenda outlines bold objectives to eliminate hunger, guarantee food security, and advance sustainable agricultural methods. However, achieving these goals is hindered by climate change and resource degradation [2], which place immense strain on agro-food systems [3]. To tackle these issues, policy priorities must focus on managing food demand, increasing productivity sustainably, addressing socioeconomic and governance issues, and expanding capacity for targeted policies, including the implementation of early warning systems to prevent food crises [4]. Implementing IoT in agriculture enables every farmer to access comprehensive data about every corner of their fields through sensors strategically placed throughout the land [5]. These sensors continuously collect crucial to the farmer's digital interface [6]. With this granular data, farmers can precisely monitor the conditions of their fields without physical presence, allowing for swift and informed decision-making [7].

For example, if a specific section of the field has insufficient moisture, the farmer can remotely activate irrigation systems to ensure optimal hydration [8]. Similarly, variations in temperature or pH can prompt adjustments in planting schedules or soil amendments, maximizing crop health and yield potential. This degree of accuracy boosts productivity while also reducing waste and minimizing environmental impact [9]. By making detailed data widely accessible, IoT enables farmers of all sizes to make informed decisions, enhancing efficiency, sustainability, and the results of agricultural practices [10]. Figure 1 shows the flow chart of how the integrated system will convey the field conditions to the user.

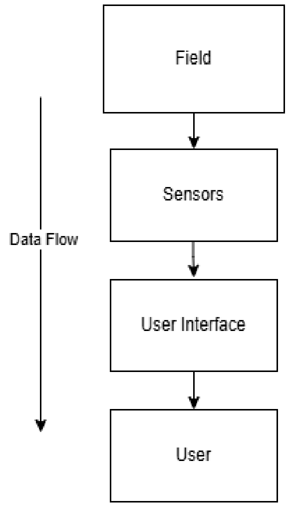

Figure 1. Flow chart of date from field to user

2. PROPOSED METHODOLOGY

Implementing IoT technology in agriculture through the strategic placement of pH, moisture, and temperature sensors across fields holds immense potential for enhancing precision farming practices [11]. Before sensor deployment, a comprehensive analysis of field topography, soil types, and microclimate variations is essential to strategically position sensors [12]. This understanding aids in optimizing sensor placement to ensure comprehensive coverage and accurate data collection. The pH sensors should be placed at multiple depths, particularly in areas prone to pH fluctuations, such as near water sources or irrigation systems [13]. Moisture sensors should be evenly distributed throughout the field, considering soil type and drainage patterns, and placed at different depths to monitor variations in soil moisture content effectively [14]. Temperature sensors should capture variations both within the soil and in the air, positioned at different heights across the field to monitor temperature differentials accurately. By strategically placing sensors based on this analysis, farmers can gather precise and insightful data on key environmental factors affecting crop growth.

Once sensors are deployed, ensuring wireless connectivity is vital for real-time data transmission, enabling farmers to access up-to-date information about their fields remotely. Technologies like long range wide area network (LoRa WAN), Zigbee, or cellular networks can be utilized depending on field size and network availability [15]. When incorporated into a centralized IoT platform or a management system for farms, sensor data can be observed to detect patterns and irregularities, supporting better decision formation. Utilizing data analytics enables farmers to gain crucial insights into soil conditions, moisture content, and temperature fluctuations, which helps them make proactive adjustments to enhance crop health and improve yield [16]. Proactive alert systems can notify farmers of critical conditions, such as pH imbalances, moisture deficits, or extreme temperatures, enabling timely interventions to mitigate potential risks and maximize productivity. Regular maintenance checks and calibration of sensors are necessary to uphold accuracy and reliability. Scheduled maintenance ensures that sensors are functioning properly and providing accurate data, minimizing the risk of errors or inaccuracies that could impact decision-making [17]. Additionally, designing the sensor deployment system with scalability in mind ensures adaptability to farm expansions or changes in configuration. As farms evolve or grow, the sensor network should be able to accommodate these changes seamlessly, allowing farmers to continue leveraging IoT technology effectively. Additionally, offering farmers education and training on how to interpret sensor data enhances the advantages of IoT technology, enabling them to make well-informed decisions and effectively optimize their farming practices [18]. By incorporating IoT technology into agriculture and utilizing sensor data effectively, farmers can boost productivity, increase resource efficiency, and support sustainable farming practices.

2.1. IoT in different crop and field conditions

IoT technology has revolutionized agriculture by delivering real-time data and insights, which enhance crop production across different fields and types of crops. On large-scale farms, IoT allows for the remote tracking of essential factors such as soil moisture, temperature, and pH levels [19]. This information enables farmers to make well-informed choices about irrigation, pest management, and fertilization resulting in better crop health and increased yields [20]. For smallholder farms, IoT solutions offer affordable and accessible technology to monitor environmental conditions and optimize resource usage. Particularly in regions with limited access to traditional farming resources, such technology can be pivotal in maximizing agricultural productivity.

Moreover, IoT systems are integral to greenhouse cultivation and aquaculture. In greenhouses, IoT systems regulate environmental parameters like temperature, humidity, and CO_2 Factors such as levels and light intensity are monitored, with automated control systems adjusting these elements to establish optimal growing conditions for different crops, this results in quicker growth, increased yields, and enhanced quality of the crops [21]. Similarly, in aquaculture, IoT sensors observe water quality criteria like dissolved oxygen, pH, and temperature as shown in Figure 2. By sustaining ideal conditions for fish and aquatic plants, farmers can boost growth rates, lower mortality, and support sustainable production. Moreover, IoT aids in optimizing the supply chain by providing traceability and transparency, which enhances food safety, quality control, and regulatory compliance [22]. Monitoring storage conditions in real-time during transport and storage helps prevent spoilage and minimize food waste, leading to a more efficient and sustainable food system.

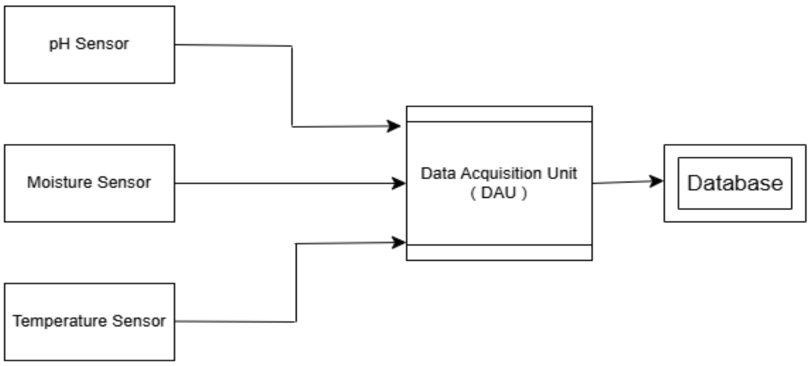

Figure 2. Integration of sensors with a local database

2.1.1. The pH sensor

The pH sensors are crucial in agriculture, providing essential information about soil health, nutrient levels, and crop development. Soil pH directly impacts nutrient accessibility, microbial activity, and overall plant development. Different crops thrive within specific pH ranges, and divergence from these optimal levels can lead to nutrient shortage and toxicities ultimately affecting both yield and quality. These sensors function by measuring the acidity or alkalinity of the soil through the detection of hydrogen ion (H+) concentrations in the soil solution [23]. Modern pH sensors, which usually include electrodes that produce an electrical signal related to the soil's pH, are often unified into IoT systems. This setup allows for real time observation and data collecting, aiding farmers to make appropriate decision.

With the advancement of agricultural technology, continuous research and development are focused on improving the accuracy, durability, and ease of use of pH sensors in farming applications. Integration with advanced analytics and machine learning algorithms holds promise for further improving the interpretation and utilization of pH data for precision farming. By utilizing these advancements, farmers can obtain more detailed insights into soil conditions and make better-informed decisions about crop management. Integrating pH sensor data into IoT platforms allows for proactive monitoring and prompt actions, which enhance crop health, optimize yields, and support overall sustainability in agriculture. Figure 3 shows the simulation shown for a specific pH which gives an alert whenever the pH goes up or down the threshold.

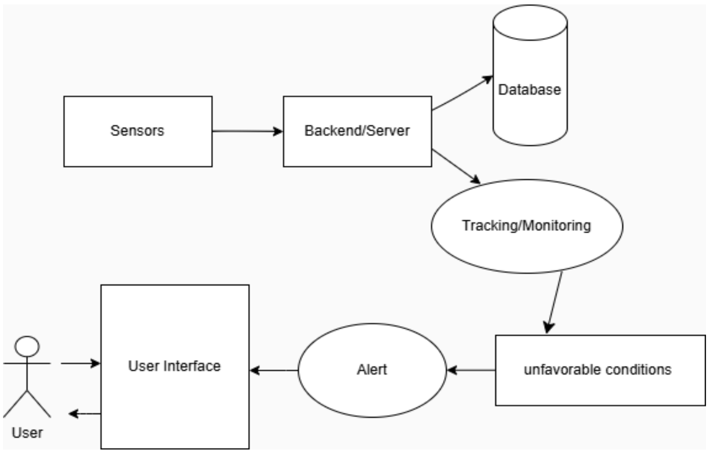

Figure 3. Integrated system for data storing and alert function for maximum yield and surveys

2.1.2. Temperature sensor

Temperature sensors are crucial in agriculture, delivering vital information for managing crop production, monitoring livestock health, and controlling environmental conditions. Temperature profoundly influences biological and chemical processes critical to agriculture, such as plant growth, seed germination, pest development, and nutrient uptake. By measuring both air and soil temperatures, temperature sensors enable farmers to monitor environmental conditions effectively. This data empowers informed decision-making regarding irrigation timing, optimal planting windows, and proactive pest management strategies. Functionally, temperature sensors commonly employ thermistors, thermocouples, or resistance temperature detectors (RTDs) to measure temperature changes accurately [24]. Thermistors and RTDs, known for their sensitivity to temperature variations, deliver precise readings within specific temperature ranges. Moreover, advanced temperature sensors may feature waterproofing, wireless connectivity, and data logging capabilities, facilitating remote monitoring and data collection. As agricultural technology progresses, ongoing advancements in sensor technology, such as miniaturization, wireless connectivity, and low-power consumption, are making temperature monitoring more accessible and efficient. Integration with IoT platforms and predictive analytics holds promise for further enhancing the utility of temperature sensor data, enabling precision agriculture and climate-smart farming practices. Figure 4 is a simulation shown for a specific temperature range which gives an alert whenever the temperature goes up or down the threshold.

2.1.3. Moisture sensor

Moisture sensors are essential tools in agriculture, crucial for improving irrigation practices, evaluating soil health, and boosting crop productivity. These sensors gauge the volumetric water content (VWC) in soil, offering important information about the water availability for plants. By monitoring soil moisture levels, farmers can fine-tune irrigation scheduling, mitigating water stress and improving water use efficiency. Additionally, soil moisture data guides decisions related to drainage systems, tillage practices, and the application rates of fertilizers, ensuring optimal growing conditions for crops while minimizing water waste and environmental impact. In terms of functionality, moisture sensors typically utilize probes or probe-connected data loggers to measure soil moisture at various depths. Capacitance-based sensors detect changes in the soil's dielectric constant, correlating with moisture content. Tensiometers operate on the principle of water movement through porous materials, with water filling a ceramic cup attached to a vacuum gauge. Although gravimetric sensors offer direct measurements of water mass in soil samples, they require more labor-intensive procedures. Looking ahead, ongoing advancements in sensor technology, such as wireless connectivity, low-power consumption, and data analytics, are enhancing the accessibility and efficiency of moisture monitoring in agriculture. Integration with IoT platforms and predictive modeling holds promise for further optimizing the utility of moisture sensor data, facilitating precision irrigation, and efficient water resource management in farming practices. Figure 5 shows the simulation diagram for a specific moisture level range which gives an alert whenever the moisture level goes up or down the threshold.

2.2. Surveys using data

Using pH, moisture, and temperature sensors in agriculture revolutionizes agricultural methods by offering real-time about soil conditions and environmental factors without the need for specialized surveys for specific fields and plots. These sensors can be deployed across agricultural fields for continuous monitoring, collecting data at regular intervals to offer a comprehensive understanding of variability and dynamics within the fields. Aggregated and integrated into a centralized database or IoT platform, this data allows farmers to access, visualize, and analyze soil health, moisture levels, and temperature variations across different areas of the farm in real time.

Furthermore, the integration of AI models, such as machine learning algorithms, with the collected sensor data enables the development of predictive models [25]. These models learn from historical data patterns and correlations between soil parameters, weather conditions, and crop performance [26]. By extracting relevant features from the sensor data and training on historical datasets paired with corresponding crop yield data, AI models can provide actionable insights for optimizing farming practices. Additionally, through a feedback loop and iterative improvement process, these models can be continuously updated and refined with new sensor data, enhancing the accuracy and reliability of future predictions [27]. This strategy enables farmers to make data-driven steps, enhance agricultural productivity, and adapt to changing situations such as conditions of the environment and market demands efficiently. Figure 5 shows how data can be stored and monitored the values from different sensors at different times for future uses of surveying the same.

3. RESULTS AND DISCUSSION

By synthesizing real time data from pH, moisture, and temperature sensors, farmers can establish ideal conditions for their crops. These sensors allow farmers to monitor soil moisture ensuring proper watering to avoid underwatering or overwatering, which can harm crops. Track soil temperature and planting at the right time and avoid frost damage. Measure soil pH and adjust the acidity/alkalinity for better nutrient uptake by crops. These features are shown by the simulations. In Figure 4 the pH Simulink simulation shows a reading of a threshold of pH values. Depending on the crop, this may indicate the soil is too acidic/alkaline. With this knowledge, farmers can add amendments, like lime or sulfur, to adjust the pH to a level that is more suitable for the crop they are growing. When the soil pH is in the optimal range, crops can more easily absorb nutrients, which can lead to higher yields. In essence, pH sensors help farmers optimize soil conditions for better crop growth.

In Figure 5, the temperature sensor Simulink simulation shows that the temperature goes below and above at different times. The system observes this and gives an alert to the farmer. By monitoring soil temperature and getting alerted when the conditions are not good, farmers can time planting appropriately. Planting seeds in soil that’s too cold can delay germination or harm seedlings. Temperature sensors can also help farmers avoid frost damage to crops by alerting them when temperatures are likely to drop. Access to real-time temperature data enables farmers to make informed decisions that may result in improved crop yields. In Figure 6, the moisture Simulink sensor simulation shows an increase in moisture level over time. This suggests that the soil is becoming wetter. If real moisture levels correspond to the simulation, farmers can be alerted at times and use this information to decide if irrigation is needed. When to adjust watering schedules. By using IoT to monitor soil moisture and getting an alert at conditions like drier or wetter than the threshold, farmers can potentially avoid underwatering or overwatering crops, which can lead to higher yields.

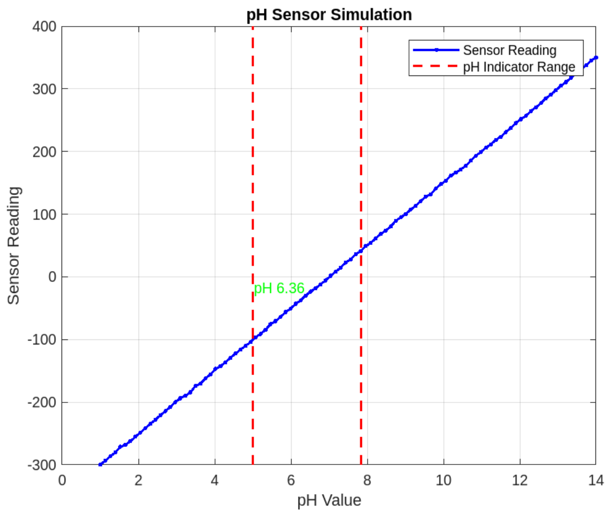

Figure 4. pH value simulation for a user specified pH level

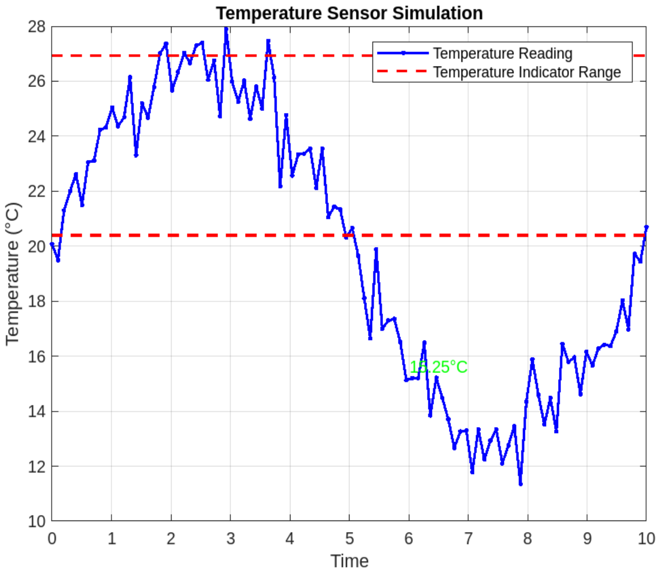

Figure 5. Temperature value simulation for a user specified pH level

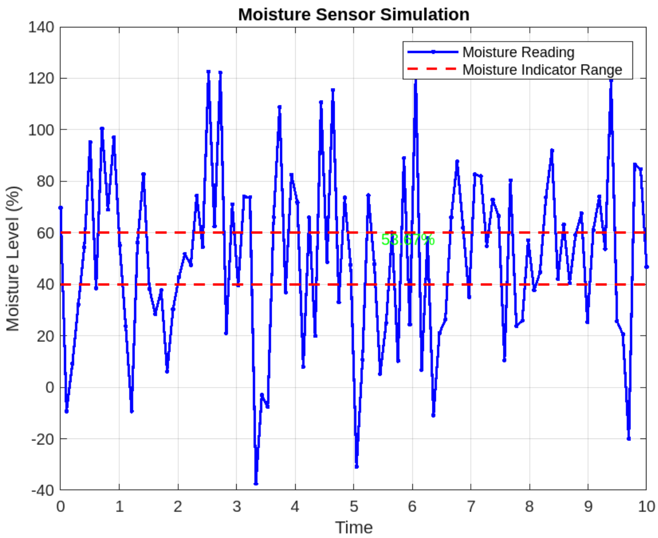

Figure 6. Moisture level value simulation for a user specified pH level

4. CONCLUSIONS

Incorporating pH, temperature, and moisture sensors into agricultural practices promises to significantly enhance crop yield. All the sensors deliver real time information on condition of soil and environmental factors allowing for accurate management of pH levels, ideal planting times, and effective irrigation. Utilizing this data informed method enables the farmers to optimize resource use, enhance soil health, and reduce environmental impact, resulting in increased yields and more sustainable farming practices. While these sensors offer a powerful tool, there's room for further exploration. Sensor Integration, research into seamlessly integrating these sensors with existing farm management systems for real-time data analysis and automated irrigation/fertilization could be highly beneficial. Advanced data analytics, developing advanced data analytics tools to interpret sensor data and provide actionable recommendations tailored to specific crops and soil types could further optimize decision-making. Sensor development continued research on sensor technology could lead to even more sophisticated sensors that measure additional vital factors like nutrient levels or pest presence. By investigating these possibilities, researchers and agricultural experts can fully harness the benefits of sensor technology, advancing agriculture toward a more sustainable and productive future.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

This article does not contain any studies with human participants or animal studies performed by any of the authors.

DATA AVAILABILITY

The datasets used and/or analyzed during the current study available from the corresponding author [SRS], on reasonable requests.

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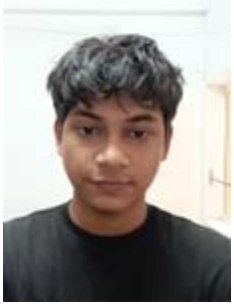

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