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IoT-based Smart Farming System

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Abstract

The integration of Internet of Things (IoT) technologies into agricultural operations, known as smart farming, presents a transformative opportunity to revolutionize traditional farming methodologies and bolster productivity, efficiency, and sustainability within the agricultural sector. This paper investigates the challenges inherent to conventional farming practices, such as inefficient resource utilization and inadequate access to real-time data to inform decision-making. By leveraging an array of IoT sensors and devices utilized for the purpose of gathering up-to-date information on various aspects such as environmental factors and animal natural behaviours, agricultural producers can gain actionable insights, facilitating data-driven decision-making to optimize resource usage and enhance crop yields. The primary objectives of this study encompass enabling automation and precision agriculture to mitigate waste and bolster productivity, while concurrently emphasizing remote monitoring and control capabilities through mobile technologies to augment overall operational efficiency and crop quality. The background underscores the critical importance of integrating IoT technologies into agricultural practices to streamline farm management processes, reduce labour requirements, and increase profitability across all scales of agricultural operations. Through the implementation of IoT-enabled smart farming solutions, this paper *endeavours* to bridge the divide between advanced technology and practical agricultural needs, offering a cost-effective and user-friendly approach to modernizing farming methodologies.

Keywords: Agricultural Technology; Internet of Things; IoT; Smart Farming

1. Introduction

Traditional agricultural practices face numerous inefficiencies and challenges hindering optimal productivity, such as inadequate monitoring of soil conditions resulting in suboptimal resource utilization and potentially diminished crop yields, as well as a lack of up-to-date information of weather conditions on agriculture productivity and plant being impeding informed decision-making processes and overall farm productivity and sustainability [1].

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A primary objective of this paper is to elucidate the implementation of an array of Internet of Things (IoT) sensors and devices to collect up-to-date information regarding essential agricultural environment factors and animal natural behaviours empowering agricultural producers with actionable insights to facilitate informed decision-making concerning irrigation scheduling, pest management, and crop health monitoring, ultimately aiming to optimize resource utilization, mitigate waste, and augment overall agricultural productivity [2].

The background of this paper examines the evolution of agricultural practices and the pivotal role of technology in modernizing farming operations. Notably, advancements in Internet of Things (IoT) technology have catalyzed the advent of precision agriculture techniques, enabling site-specific management of inputs, thereby enhancing efficiency and sustainability [3]. This section underscores the burgeoning demand for sustainable farming practices and the exigency for innovative solutions to address the multifaceted challenges confronting farmers in today's dynamic agricultural landscape [4]. The integration of IoT sensors and devices enables the acquisition of up-to-date information concerning essential environmental factors and animal natural behaviours, empowering agricultural producers with actionable insights [5].

Related Work

The deployment of IoT-based solutions in agriculture has recently emerged as a promising approach that can improve productivity, efficiency, and sustainability in farming practices. There are various studies that highlight the advantages of implementing IoT in agriculture for real-time monitoring, early disease detection, precision irrigation management, and so on. In this section, three research articles are analyzed based on the methodologies, challenges, and future directions of their proposed IoT smart farming system.

The research done by Gagliardi et al. studies the use of information and communication technology (ICT) in agriculture. With the help of automation, image analysis, and artificial intelligence (AI), it allows farmers to have real-time monitoring of their crops and precise automated treatments in their farms [1]. The proposed smart farming design integrates various smart systems, including web-based applications, UAVs, multi-spectral cameras, sensors, etc for achieving a precision farming system that allows farmers to have better management of their crops. The features of the proposed system include the processing of video and images, wireless data exchange, real-time data analysis, and data evaluation from the weather data [1]. The proposed system offers several advantages, including enhanced crop yield and quality, decreased expenses, optimized utilization of data inputs, and reduced environmental footprint.

Moreover, another research by Jadhav et al. tackles a significant problem arising in the agricultural industry, which is the increase in food demand leading to difficulties in ensuring sustainability and resource efficiency. They proposed an IoT-based smart farming system that utilizes IoT devices like sensors to collect crop field data from the farm [6]. Data analytic techniques are used to analyse the data to help farmers make informed decisions by sending notifications to the farmer’s phone to notify the farmer about the condition of the farm. The integration of IoT in their proposed system allows for higher crop yield while reducing the costs and environmental impacts [6].

Furthermore, for livestock monitoring, a study by J Aparna Priya et al. proposed an IoT-based livestock monitoring system that allows farmers to have real-time monitoring of the livestock’s health status. This enables farmers to perform quick treatments on animals with abnormal health conditions to prevent the spread of infectious diseases, track grazing animals to prevent loss, optimize breeding practices, and so on [7]. The proposed system uses IoT sensors like body temperature sensor cable, heartbeat sensor, and rumination sensor to track the health status of the livestock, a Raspberry Pi connects the sensors and transmits the data to a cloud server to then be accessed from the mobile application. The benefits achieved from the proposed system are the ease of diagnosing the health conditions of the livestock and allow for immediate veterinary consulting for any abnormality detected to ensure early treatment to prevent the worsening of the illness [7].

Methodology

In this section, the materials and methods used in designing and implementing the IoT smart farming system are discussed in detail. This includes the hardware and software components, system architecture, and prototype development.

System Design

Fig. 1 shows the block diagram of the proposed smart farming system. It depicts the hardware components used to design the prototype and how they interact with each other to achieve the smart farming practice.

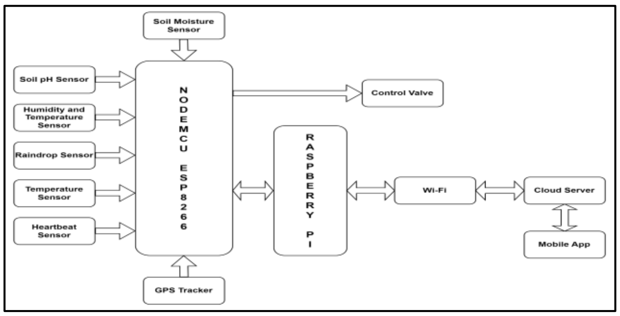

Fig. 1. Block diagram of smart farming system

- **NodeMCU ESP8266**: The NodeMCU is a type of microcontroller that has a built-in ESP8266 Wi-Fi module. It can be programmed using the Arduino IDE using C/C++ programming language or Lua script [8]. This microcontroller is suitable for handling the Wi-Fi connection between the IoT sensors and devices before connecting to the Raspberry Pi.
- **Raspberry Pi:** The Raspberry Pi is a low-cost and small-sized computer that can be plugged into an external monitor, keyboard, and mouse [7]. Programming languages such as Python, C++, and Java are normally used to program it. One of its uses is to establish a connection to the NodeMCU to then send signals to the control valves to execute the commands from the user or application since it can handle more complex programs.
- **IoT devices:** The IoT devices used include a soil moisture sensor, soil pH sensor, humidity and temperature sensor for the crop monitoring system; temperature sensor, heartbeat sensor, and GPS tracker are used in livestock monitoring. Besides, the control valve is essential in regulating the irrigation process by controlling the flow of water and fertilizers.
- **Arduino IDE:** The Arduino IDE is a software platform that allows Arduino boards to be programmed. Although it is generally used for programming Arduino boards, it is also designed to work with other kinds

of microcontrollers. In this project, it is mainly used for programming the NodeMCU ESP8266 microcontroller. The programming languages supported by the Arduino IDE include C/C++ languages and also Lua script [9].

- **ThingSpeak:** ThingSpeak is an IoT analytics platform service that includes services like cloud-based data visualization and analysis of live data. The ThingSpeak API collects incoming data, timestamps it, and gives the output for users and machines [7]. ThingSpeak enables users to create applications for data collection, data processing, and simple data visualizations utilizing the data collected from the sensors.
- **Android Module/App:** The proposed smart farming system consists of a mobile application for the farmers to utilize as a centralized dashboard. The module is installed on the farmer's smartphone as an Android app and they can use it to access the precision irrigation feature, and monitor of crops and livestock conditions by connecting to the Thing Speak Cloud. Equations

Communication architecture

Based on the listed hardware and software mentioned, in this section, the communication architecture will be discussed to describe how to connect the hardware components and software together to work as one smart farming system.

First and foremost, the NodeMCU ESP8266 microcontroller connects to the sensors to collect the crop field and livestock data. The ESP8266 Wi-Fi module allows the microcontroller to connect to the sensors via Wi-Fi connection, reducing the need for complex wiring as it is difficult to use wires for connecting in a large area like a farm. Using the Arduino IDE, some basic coding is required to set up the Wi-Fi connectivity, initialize the sensors, and handle the data collection and transmission. After the code is written, it can be uploaded to the NodeMCU to then establish the connection of sensors to the NodeMCU.

Moving on, the NodeMCU microcontroller is connected to the Raspberry Pi. Since the Raspberry Pi can handle more complex programs that are written in Python scripts, data analytics programs like disease detection for crops and livestock can be written using the Thonny IDE and then uploaded into the Raspberry Pi. The Raspberry Pi acts as the medium that receives the sensor data from the NodeMCU and sends commands to the motors connected to the water valves or feeders to initiate the necessary functions.

Next, in order to transmit all this data to a cloud server, in this case, the ThingSpeak Cloud, the MQTT (Message Query Telemetry Transport) is chosen as the main communication protocol to connect the devices to the cloud server. This is because the smart farming system requires frequent data updates from the sensors, with the publish/subscribe model of MQTT it allows for more efficient data transmitting due to it reducing the need for constant polling. Moreover, MQTT is a lightweight protocol, making it more suitable for implementing the smart farming system since most farms are located in areas with limited bandwidth. In addition, MQTT's scalability allows for efficient communication within systems that consist of a large number of devices [10].

Lastly, using ThingSpeak to create simple visualizations of the sensor data, these visualizations can be uploaded to the Android app in the farmer's smartphone for them to monitor the real-time data of the crop field and livestock. The programmed functions like precision irrigation, smart feeding, and so on can also be accessed from the Android app to send commands to the Raspberry Pi to then execute the commands by sending the signals to the motors connected to the respective end devices.

Mobile applications prototype

In this section, the prototype of the smart farming mobile application is provided in the figures below with descriptions. The mobile application acts as a centralized dashboard for the farmers to monitor the conditions in their farm all at one stop at their fingertips. Fig. 2 displays the crop monitoring interface that displays the overall crop field information.

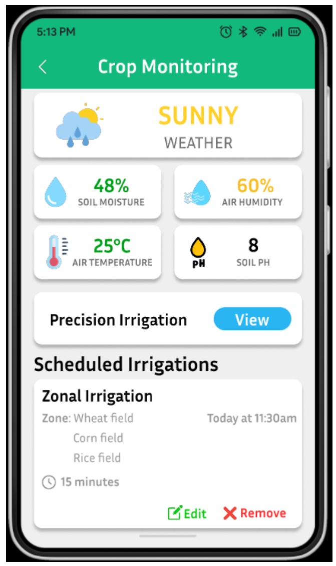

Fig. 2. Crop monitoring interface

Based on Fig. 2, data such as the soil moisture level, pH level, weather, air humidity, and air temperature are displayed on the top of the interface. At the bottom, it displays the scheduled irrigations set previously for different areas in the farm. If the farmer wants to look into more detailed information of each crop field, they can press the Precision Irrigation "View" button to navigate to the next page as shown in Fig. 3.

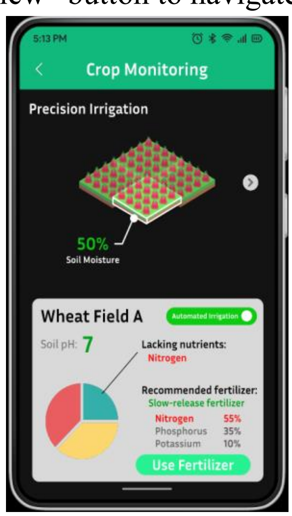

Fig. 3. Precision irrigation interface

In this page, the farmer can monitor each crop field's conditions separately. Moreover, it also displays what the crop field is lacking in terms of nutrients and recommend a fertilizer for the farmer to use to address the lack of a specific nutrient. Farmers can also select whether to turn on the automated irrigation settings.

Lastly, the livestock monitoring interface is shown in Fig. 4 It displays the livestock's health status and movement heatmap. The body mass line graph allows the farmer to manually enter the livestock's mass after they weighted it.

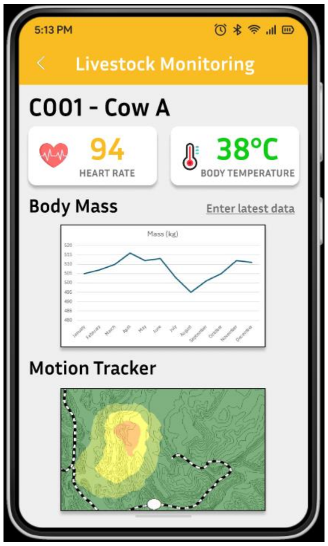

Fig. 4. Livestock monitoring interface

Circuit prototype

In this section, the prototype of the component circuit for certain functionality involved in the system will be discussed and explained clearly with the sample circuit given.

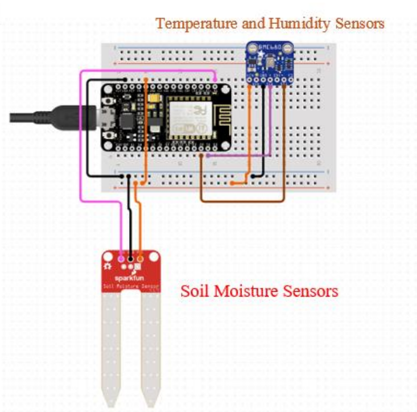

Fig. 5. Sensing Component for moisture temperature and humidity

As shown in Fig. 5, the sensors will be connected to NodeMCU which is powered by a wire cable. Once the environmental factors are captured by the sensors, they will be converted to an electrical signal and transmitted to the NodeMCU through the wire, and from the NodeMCU, the signal will be converted to a data package based on the configuration and transmitted to the Raspberry Pi, which is the centralized data processing unit.

To ensure the mobility and reliability of the sensing component, the component will be required to be powered with a mobile power supply, for instance, batteries. Thereby, certain research has been made by the team, and finally, a solution will be referred to in the Fig. 6.

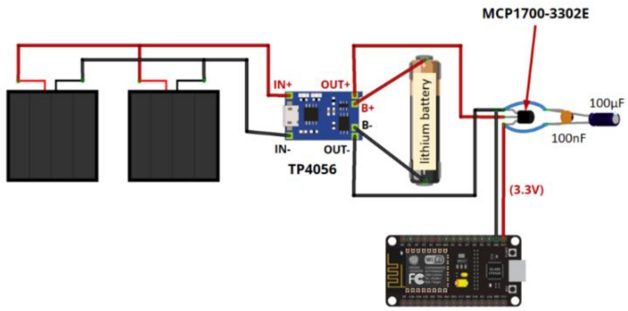

Fig. 6. Power supply using solar panel and lithium battery [11]

As the figure shows, the solar panels were connected to a component TP4056 which is a charging module for circuit protection to prevent the overvoltage of rechargeable lithium batteries and also reverse the polarity connection. Meanwhile, the power regulator component, MCP1700 was implemented followed with the ceramic capacitor and electrolytic capacitor to smoothen the voltage peak for the operation of the NodeMCU in our sensing component.

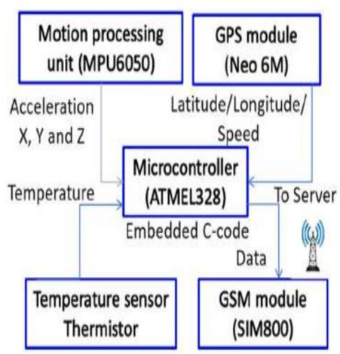

Fig.7. livestock monitoring block diagram [12]

In Fig. 7 shows, ATMEL328 was implemented as the microcontroller for this component in the research [12]. The data will be transmitted to the server using the GSM module, SIM800 in the figure. However, the design is not applicable for our project, thereby, the component ATMEL328 and GSM module will be replaced by NodeMCU, which is smaller and cheaper. The signal from the sensors and the GPS module will be transformed into a data package and transmitted to the centralized data processing unit through the network connection to reduce the implementation difficulty.

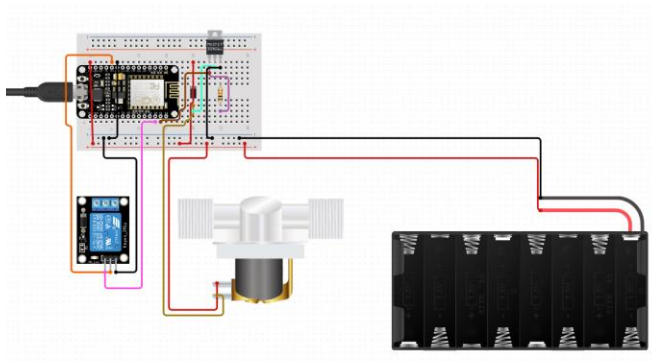

Fig. 8 Solenoid Valve for precision irrigation

To achieve precision irrigation, a simple circuit connected to NodeMCU had been designed in Fig. 8 for the scenario. In the figure, the circuit was powered by the batteries, however the farmers could also have the power supply and lithium in Fig. 6 as the power supply for this circuit. In this circuit, a relay module had been implemented to the circuit to control the circuit from on and off to prevent access water or fertilizer usage.

Architecture Diagram

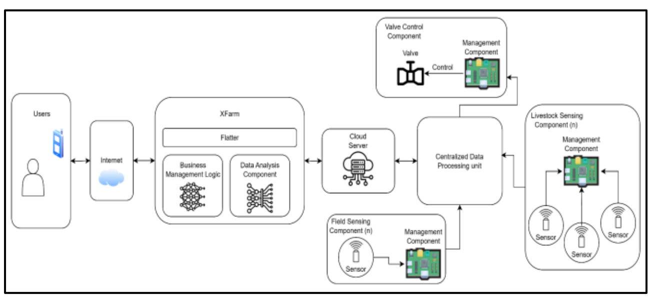

Fig. 9 Architecture Diagram

Fig. 9 above shows the architecture diagram designed for the system, including the physical component, to demonstrate how are the sensing components connected to each other.

In this system, users can only access our application using their mobile devices, including tablets or smartphones. To maximize our market competence power, our application will be compatible with both IOs and Android platforms, furthermore, the IoT devices in the system will have a simple structure, allowing the components to connect to each other easily and able to connect with other IoT devices which is not developed by the company.

The mobile system will be developed using Flatter, which is an open-source mobile application development platform. By using Flatter, the team could develop the application without any financial concern during the development process, as all related documentation will be open-sourced and free to access. Meanwhile, the software will involve Python language for data analytics and data visualization purposes.

The database of this system will be involved in cloud solutions to prevent any extra financial costs for device maintenance and implementation. Meanwhile, the scalability and flexibility of our system could be ensured to fit any business expansion or user onboard. The sensing component will be designed as mentioned above, and they will be connected to each other using WiFi connection. The data will be captured by the sensors in the sensing components, then transmitted in a data package to the centralized data processing unit, which is Raspberry Pi. The Raspberry Pi will need to save the data to the on-cloud server. Hence the system could visualize the data and show it to the users through the mobile applications.

Discussion

As the industry revolution began, the terms of Artificial intelligence, IoT devices, and smart system are getting familiar among people. Since 2010, the trends of Google responses to the term “Internet of Thing” or “IoT” are increasing gradually [13]. Besides, the related terms, such as “Smart Farming” or “Precision Irrigation” had been increasing since 2015 [13].

The research done by A. Khanna and S. Kaur[13], indicates the public has started to pay attention to the implementation of IoT smart systems in agriculture activities. Meanwhile, the implementation of Machine Learning has also proven to have a positive impact on agriculture activities through IoT devices and smart systems. For instance, the implementation of K Nearest Neighbor (KNN) had achieved fully automated irrigation [14]. According to the research, the irrigation will be decided by the algorithm fully after analyzing the moisture and temperature data collected by the sensors placed in the field. The experiment had been conducted and had a very positive impact on the agriculture yield in the experiment area.

Meanwhile, the research indicates the implementation of a decision-making system along with the IoT devices could help to predict and detect the disease among the potato plants [15]. Despite the experiments being done in an experiment field, however, this study possesses the potential to implement the technology the large crop farms.

From the research made, it is clearly shown that the implementation of the IoT smart system into agricultural activities will bring various positive impacts to farm yield. By increasing the farm yield, the farmers could earn more income by selling the farm products as well. Meanwhile, the research done by Y.Akkem et al[16] indicates that the implementation of the artificial intelligence algorithm, for instance, ARIMA, recurrent neural network (RNN) and KNN could help in predicting the farm yield using the collected time-series data. Meanwhile, the algorithm could also perform the predictions in the soil fertility classification and crop selection [16-22].

From all the case studies, the implementation of the smart system to agricultural activities could help in this industrial revolution. Compared with the studies made, the products or technology invented had only focused on either irrigation or livestock monitoring, unlike the technology mentioned in this study which could cover all of them with a lower cost due to the unique architectural design [23-30].

Due to the simplicity of the system, the users or farmers will not require any technical knowledge in the implementation of the system, which creates product differentiation from other products. In this case, the system will have greater competence power than the others, resulting in better preference for the users. The limitation of the product will be the limited technology level and limited computation power possessed in the data processing unit [31-39]. To reduce the costs of the implementation, the components selected will need to achieve maximum computational power with limited expenses. Meanwhile, to ensure the accuracy of the analysis given the system, various numbers of sensing components and centralized processing units will need to be implemented in the field, which might be heavy costs for the farmers with larger areas of the farm [40-46]. In this way, it will further increase the difficulty of implementation and concerns in component maintenance due to the large number of sensing components implemented.

2. Conclusion and future work

In conclusion, the smart farming solution presented here is a significant advancement in agricultural technology that gives farmers new tools to increase efficiency, sustainability, and productivity. Through the integration of precision irrigation management, smart feeding, crop monitoring, and livestock health monitoring, the system empowers farmers to use data to make well-informed decisions and streamline essential procedures. Farmers can easily access real-time information and control features through the user-friendly mobile interface, which enables them to manage their operations remotely and react quickly to changing conditions. Smart feeding, automated fertilization, and automated pest control are examples of automated procedures that minimize labor costs and increase yield.

However, there are still certain things that could be improved and optimized. To provide more precise predictions of crop and livestock health, future research may concentrate on improving predictive modelling capabilities through sophisticated AI and machine learning algorithms. Exploring the potential of edge computing can significantly enhance the efficiency and responsiveness of smart farming systems as well. Smart farming solutions that incorporate edge computing can improve scalability and resource efficiency, particularly in places with limited connectivity or high-cost data transmission. This method makes smart farming more resilient and economical by reducing reliance on centralized cloud infrastructure while simultaneously increasing system performance. Furthermore, protecting sensitive farm data and upholding regulatory compliance will require constant efforts to enhance data security and privacy protocols. By cost-effectively integrating new technologies like blockchain, the agricultural supply chain's traceability and transparency may be improved, boosting consumer confidence and farmers' access to markets.

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