Digital Twining in Intelligent Farming Systems

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Abstract

The agriculture industry needs to adopt the latest technologies to manage and market crops in a more efficient manner. By using IOT and other digital solutions, farmers can increase their yield and profitability by streamlining the process of controlling and marketing their crops. Digital farming aims to provide customers and farmers with a range of solutions to address current issues such as resource management and food security. With a complex set of variables to consider, such as climate change, digital techniques can significantly improve decision-making support and efficiency. Digitalization can also help prevent crop hoarding and establish optimal prices for crops throughout the year. By using digital twins, all crop availability can be displayed in one location, making contract farming possible without needing a large number of fields in one area. This approach can encourage corporate investment in agriculture and increase the export of crops between countries. Additionally, the use of digital twins allows us to keep track of all services, agreements, and transactions between farmers and merchants on a transparent platform. Using IOT devices that utilize machine learning algorithms, we can automatically determine relevant prices and check the quality of crops. This will enable farmers to get the best value for their crops while providing consumers with high-quality produce. Overall, digitalization can revolutionize the agriculture industry and help us address current and future challenges.

Keywords
IOT, Digital Twins, Machine Learning, Crops Management, Crop recognizing device.

1. Introduction

The use of digital twin technology in combination with IoT systems can significantly improve crop management and sales. Digital twin technology involves creating a virtual replica of a physical object or system, which can be used to simulate and analyze different scenarios and outcomes. In the context of crop management, a digital twin can be used to model a specific farm, taking into account factors such as soil quality, weather conditions, irrigation systems, and crop types.

Real-time data on various aspects of the farm, such as soil moisture levels, temperature, and humidity, can be collected using IoT systems. This data can be used to update the digital twin and make predictions about future crop yields, potential pest outbreaks, and other factors that could affect the success of the farm.

Digital twin technology and IoT systems can also be utilized for crop selling. Data on crop quality, quantity, and market prices can be collected and used by the digital twin to predict the best time to sell the crops for maximum profit. In addition, IoT sensors and digital twins can assist farmers in optimizing their crop management practices by identifying areas for improvement, such as modifying irrigation schedules or utilizing different fertilizers. This can result in increased crop yields and a more efficient and environmentally friendly farming operation. The combination of digital twin technology and IoT

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systems has the potential to transform crop management and sales, empowering farmers to make decisions based on data that leads to increased efficiency, profitability, and sustainability.

The paper is divided into 5 sections. Section 1 gives the overview of the digital twin technology in crop management. The remainder of the paper is structured as follows, Section 2 briefly describes the Systematic Literature Review (SLR) and digital twin terminologies, its uses in data analyzing and integration levels. The concepts of contract farming and "one nation- one market" is also briefed in this section. Section 3 looks to conceptualizes the methodology using NoIR IOT based camera used in crop recognizing. Results are discussed in section 5. Finally, the paper concludes in Section 6.

2. Background Study

In many countries, the increasing population results in a shortage of agricultural land and food supply. Reports suggest that hunger-related factors cause the death of 20 million people every year. The Food and Agriculture Organization (FAO) estimates that there are currently 435 million severely malnourished people in the world [1]. Despite this, almost 2.5 billion tonnes of food produced annually is lost or wasted, with one-third of it being lost during the production process. According to the Boston Consulting Group (BCG), the value of this wasted food is estimated to be $230 billion [2]. Some countries, like India, are facing a food surplus crisis, as reported by the Food Corporation of India (FCI). The buffer stocks in India contain 30 lakh tonnes of sugar, 221 lakh tonnes of rice, and 478 lakh tonnes of wheat [3]. This highlights the mismanagement of food resources and the need for digitalization to address this issue. Fortunately, there are many modern technologies and methods that can help to regulate poor food management and save countless lives. Many nations, such as Liberia 76.9%, Somalia 60.2%, and Guinea-Bissau 55.8%, rely heavily on agriculture as a major contributor to their economy [4], with the sector accounting for a significant portion of their GDP. Therefore, it is crucial for these countries to have efficient and transparent crop management systems that can improve the quality and quantity of their crops and generate greater profits. To achieve this, advanced technologies can be utilized to create automated crop management and distributed systems.

Crops are categorized based on several factors such as growth and maturation, root depth, climate, season, and carbon dioxide absorption [5]. During harvest season, there is a surplus of supply and equal demand, causing crop prices to decrease automatically. Farmers who rely solely on crops for income sell their produce at a lower price and may not make any profit. Conversely, after harvest season, there is a shortage of crops and equal demand, causing prices to rise, making it costly for customers to purchase the same food. This results in a loss for producers during harvest season due to the high supply and for consumers after the harvest season due to low supply. To mitigate this problem, technology and digital twin methodology can be utilized to set prices for every crop for the entire year, ensuring that prices remain stable during and after harvest. This will enable both farmers and consumers to make a profit since prices will remain constant throughout.

Many farmers across the country are facing losses as they have to purchase all their inputs, such as seeds, fertilizer, and other supplies, at retail prices and sell their produce at wholesale costs [6]. This is in contrast to the manufacturing industry, where raw materials are bought at wholesale prices and products are sold at retail prices. Through the use of digitization, we can provide farmers with inputs at wholesale prices, reducing their production costs and increasing their profits. Despite the fact that 47 countries have implemented 67 reforms to assist farmers in growing their businesses, many farmers are still unaware of these programs and are missing out on their benefits [7]. By digitizing the agricultural sector, we can quickly disseminate useful information to farmers and reduce the number of struggling farmers.

Digitizing the agriculture sector can help farmers who struggle to sell their crops at a profitable price by providing them with access to technologies. Additionally, small-scale and marginal farmers often cannot afford high-quality seeds due to their high cost and limited availability in nearby stores.

However, the quality of the seed used in farming is crucial for achieving higher crop yields and sustained agricultural productivity. Ensuring high-quality seed distribution is just as critical as seed production [8]. By leveraging digitization, we can provide door-to-door services to farmers and monitor the availability of high-quality seeds in their area, thereby addressing this issue.

Farmers in certain regions may not be familiar with the latest technologies available for agriculture. The lack of proper equipment is a major challenge faced by farmers, making it difficult for them to adapt to modern agricultural practices. However, with adequate training, farmers can significantly improve their lives and the productivity of their farms. The use of modern equipment is crucial for this purpose. Through digitization, we can provide farmers with access to new technologies that can greatly benefit them.

Farmers face numerous daily challenges, resulting in their status as price takers rather than price makers. Additionally, the global population is growing exponentially. In this context, ensuring food security for the world's expanding population while ensuring long-term sustainable growth is a crucial goal. To achieve this, we must implement the "One Nation, One Market" principle by leveraging digital twins and cutting-edge technologies such as IoT and other advanced technologies.

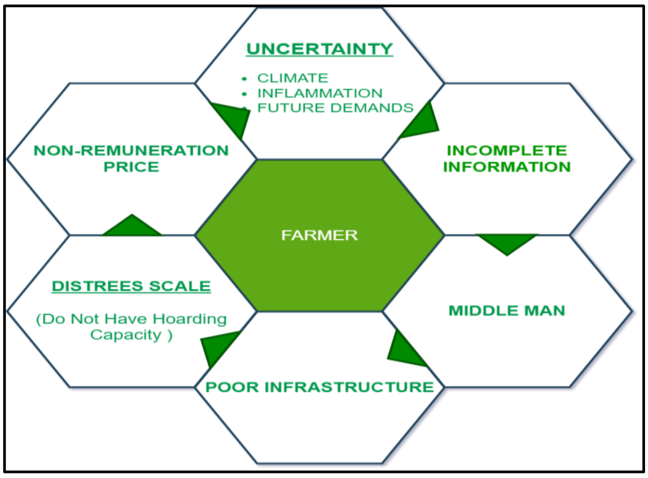

Figure1. Issues faced by farmers

By eliminating intermediaries and facilitating direct communication between farmers and retailers through digitalization, agricultural prices can benefit both parties. Various advanced technologies are available in the market that can be utilized to establish a system that enables seamless connection between farmers and retailers.

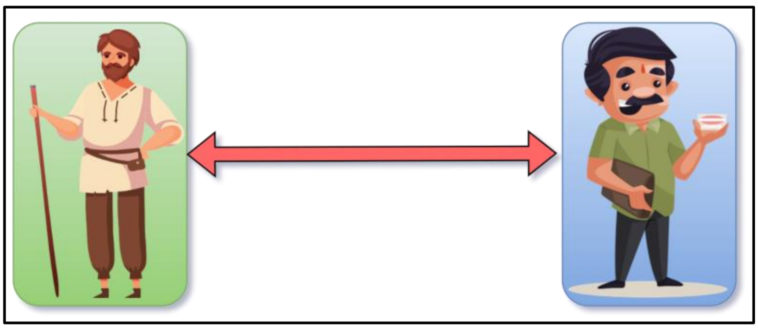

Figure2. Direct communication between farmers and retailers

In many regions, farmers lack literacy and are not familiar with modern technologies, making it difficult for them to adopt digitalization in agriculture [9]. Hence, to make the agricultural sector more digital, it is crucial to design user-friendly digital services with simple graphical user interfaces that can be easily used by anyone with basic computer skills, ensuring accessibility and convenience for all.

2.1. Modeling terminology of a Digital Twin

A Digital Twin is a digital representation of a physical object or system, which is used to simulate and analyze its behavior in real-world conditions. The following are some common modeling terminologies used in Digital Twin development:

1. Model: The Digital Twin model represents a physical object or system through a mathematical model that includes data on its design, construction, operation, and maintenance.

2. Inputs: Inputs for the Digital Twin model include various types of data, such as sensor readings, environmental conditions, and user inputs, used to simulate the behavior of the physical object or system.

3. Outputs: Outputs generated by the Digital Twin model can provide performance metrics, predictive analytics, visualizations, and other data-driven insights, based on the inputs fed into the model.

4. Simulation: Simulation involves running the Digital Twin model to predict how the physical object or system will behave under different conditions, allowing potential issues to be identified and performance to be optimized.

5. Validation: Validation involves verifying that the Digital Twin model accurately represents the physical object or system by comparing the model outputs to real-world data.

6. Optimization: Optimization is the process of using the Digital Twin model to identify ways to improve the performance of the physical object or system, including changes to design, maintenance, or operational processes.

7. Machine learning: Machine learning is a type of artificial intelligence that enables the Digital Twin model to learn from data and improve its predictions over time, helping to identify patterns and optimize performance.

8. Analytics: Analytics involves using data to gain insights into the performance of the physical object or system, which can include descriptive, predictive, and prescriptive analytics.

The use of digital technology can enable farmers to engage in contract farming, which involves an agreement between farmers and processing and/or marketing firms for the production and supply of agricultural products at predetermined prices [10]. By leveraging digital twin technology, individual farmers can easily participate in contract farming. This can provide small farmers with access to new markets that would otherwise be inaccessible to them.

There are various types of crops available, and the price of each crop is determined by its quality. However, assessing the quality of crops can be challenging for humans to do accurately with the naked eye. Hence, utilizing machine learning (ML) and Internet of Things (IoT) technology can help verify the quality of crops and establish prices based on their respective quality levels.

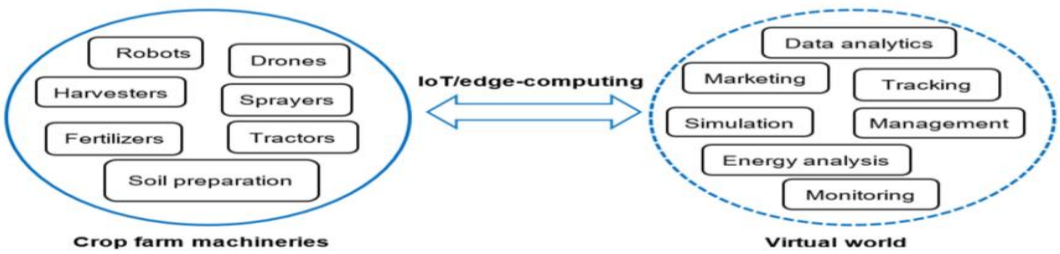

Figure3. showing crop farm machineries and virtual world outcomes using IOT/edge-computing

2.2. Digital Twin at data integration level

A digital twin is a virtual representation of a physical system or process that enables real-time monitoring, analysis, and optimization. In the realm of data integration, a digital twin can be employed to create a unified view of data from multiple systems or sources.

To generate a digital twin for data integration, you must first identify the various systems or sources that you want to integrate. These sources may comprise databases, APIs, file systems, and other data repositories. You must then develop a data model that represents the structure and relationships of the data in each of these sources.

Subsequently, you can employ this data model to create a digital twin of the integrated data. This could involve creating a virtual database or data warehouse that consolidates all of the data from different sources, or it could involve generating a real-time data stream that aggregates data from multiple sources as it is made available. The digital twin can be utilized for a range of purposes, such as real-time data monitoring and analysis, forecasting future trends and outcomes, and optimizing processes based on data insights. With the aid of advanced analytics techniques, including machine learning, the digital twin can even be used to automate decision-making processes and enable autonomous operations.

2.3. Digital Twin in Contract Farming

a. Contract farming
   Contract farming (CF) involves an agreement made in advance between farmers (producers) and buyers for the production and distribution of agricultural products, where the terms and conditions are agreed upon by both parties. These terms often include the price to be paid to the farmer, the quantity and quality of the product required by the buyer, and the delivery date of the product to the customer. The contract may also specify details on how production will be carried out or whether the buyer will supply inputs like seeds, fertilizer, and technical guidance [11].
   CF has been used for many years, but its use has increased in recent times, especially in developing nations, due to the growing demand for food and agricultural products brought on by globalization. As more people live in cities and seek food that is safe to consume and produced in an environmentally friendly and socially responsible manner, food markets have become more competitive. In this new environment, agricultural product buyers must collaborate more closely with their supply chain partners to obtain high-quality raw materials directly from farmers and satisfy the demand for food products from their clients, including supermarkets, eateries, hotels, schools, and hospitals.
   Contracting with farmers can help businesses that process agricultural goods ensure a steady supply of raw materials that match their quality and quantity requirements.

b. How Digital Twin use in Contract Farming (CF)
   The main challenge associated with contract farming is that small-scale farmers with limited land holdings are often unable to participate because the firms require a minimum quantity of crops from a single location. However, advancements in technology, such as the digital twin technique, have made it possible for individual farmers to engage in contract farming. By creating a virtual community of farmers interested in contracting with the same business, we can connect and facilitate their participation digitally. While implementing this solution is complex and poses real-world challenges, it is feasible with the latest technologies and commitment. It is important to consider that many farmers around the world may be illiterate and lack the necessary infrastructure to use such advanced methods. Therefore, a user-friendly system with simplified processes and a one-click service can be created to make it accessible to everyone.

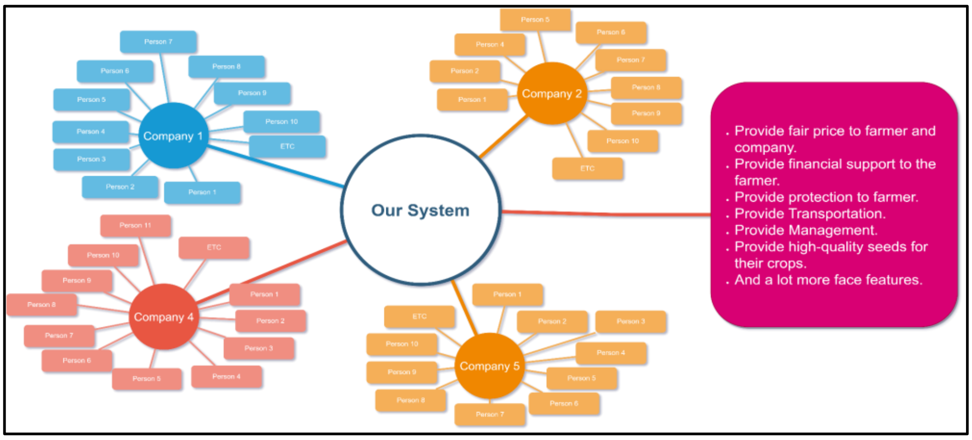

Figure4. showing crop farm machineries and virtual world outcomes using IOT/edge-computing

In the digital realm, the combination of technology and human effort can make anything possible. Consequently, it is feasible to quantify crop production by utilizing digital tools, and we can also assess the quality of crops through specialized machine learning algorithms.

2.4. Digital Twin in "One Nation One Market" Strategy

Each country is comprised of multiple states or districts, and each district in turn is composed of several small villages. In some states, the production of certain crops is high, while in others, it is low. Consequently, the demand for specific crops can be higher in some regions than in others. If digital platforms are utilized to gather crop production data during the harvesting season, it would be possible to predict the crop production levels for each state based on the demand. This would allow for the calculation of crop prices for the entire year. If production exceeds demand, exporting crops becomes feasible, and farmers can reap more financial benefits, while consumers would be content with buying crops at a consistent price throughout the year. This approach can prevent crop hoarding in the country, help each state acquire crops at a reasonable price, and encourage private sector investment in agriculture.

2.5. Digital Twin in Data Collection

By utilizing Digital Twins as the primary tool for farm management, physical flows can be separated from planning and control. This allows farmers to remotely manage operations using (almost) real-time digital information, eliminating the need for on-site human labor and direct observation [12]. By assembling information from various sources, such as weather stations, drones, and soil moisture sensors, farmers can gain insight into the status of their crops, the condition of their land, and weather patterns. The latest technologies, including advanced AI and ML algorithms, make all of this possible. In fact, emerging trends in the computer industry, such as blockchain technology, cloud computing, the internet of things (IoT), machine learning (ML), and deep learning (DL), have already been applied by researchers to address complex problems in fields such as healthcare, cybercrime, biochemistry, robotics, metrology, banking, medicine, and food [13].

2.6. Digital Twin in Data Analyzing

By automating analytics through the Internet of Things (IoT) and other machine-driven methods, we can obtain various data from sensors and other sources without the need for human intervention [14]. Farmers can use the digital twin they have in place to simulate different scenarios and make predictions about the outcomes. The analysis can assist farmers in optimizing their crop management techniques, increasing crop production, and improving resource efficiency. By analyzing the collected data, they can predict soil composition and capacity, create digital product descriptions, forecast weather patterns, identify persistent stress factors, and much more. Several companies are employing Artificial Intelligence (AI) and other technologies to model and forecast weather, which can be integrated into our agricultural digital twin. Understanding the soil's composition and capacity where crops are grown is a critical aspect of land-based agriculture. In order to create an agricultural digital twin, we must measure and comprehend this information and take appropriate action, such as changing irrigation or fertilizer application, based on data analysis. By pinpointing areas and processes where the agricultural system's resources are under stress, we can reduce water usage and fertilizer waste. Identifying and addressing issues such as invasive species, poor soil quality, and pollution through careful analysis and inquiry, such as "How might we," can significantly improve agricultural performance. With the ability to plan, analyze, and simulate crop growth, we can increase yields, reduce strain on water resources, and improve soil quality.

2.7. Digital Twin in Monitoring and Refining

It is important to monitor the crop health and gather data consistently throughout the entire cycle. As more data is accumulated, the digital twin can be refined and crop management can be adapted accordingly.

3. Methodology Used

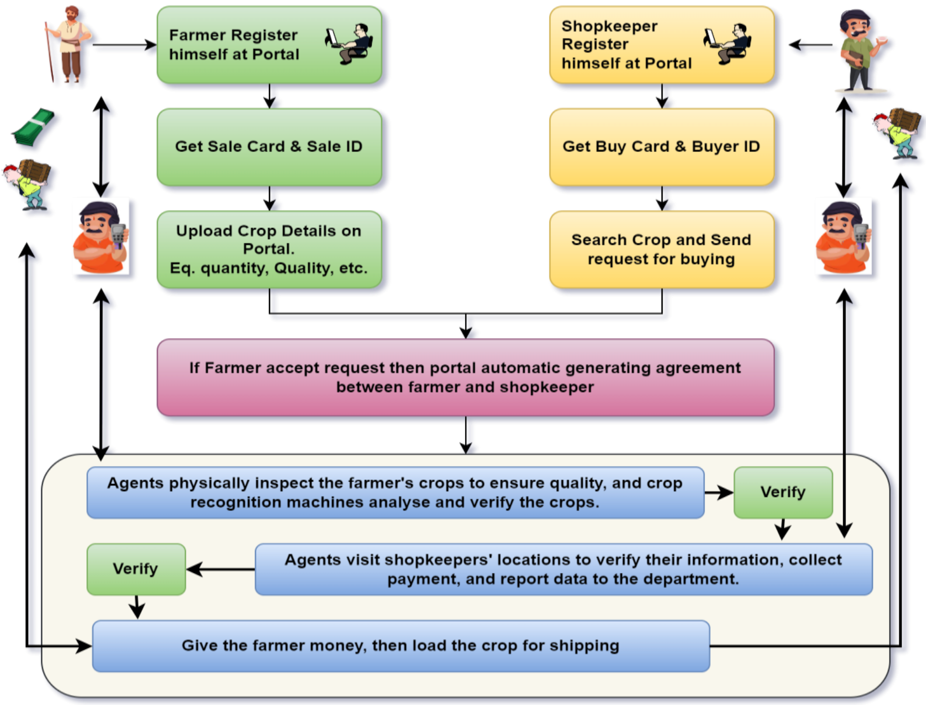

Figure5. Methodology Used

The above presented methodology represents a transparent system, utilized by both literate and illiterate farmers. The registration is required for both farmers and shopkeepers for gathering information, assistance can easily be provided through nearby cybercafes and govt agencies. After successful registration, farmers can submit their crops' quantity and quality with a single-click based system in this application or server as shown in Figure 5 as discussed below:

- A shopkeeper approaches the farmer after a farmer upload crops in order to buy those crops and sends a request to buy crop.
- If farmer accepts the request, then portal automatically generates an agreement between the farmer and shopkeeper.

- System is able to create automatic agreements, which can act as a proof of transactions done between farmers and shopkeepers.
- When farmers are ready to sell their crop and shopkeeper are ready to buy crops then a physical verification is required to check the quality and quantity of crops to finalize the transaction.
- Therefore, an agent (Human) goes to farmer house and check the crop quality and quantity and also check the quality of crop by using Al algorithm-based machine. The unit is comprising of a Pi NoIR infrared powered camera which captures the images of the crop and check the quality of crops.

Crops are ready to be sold when everything is in order. If everything is in order, farmers should find a way to transport their goods to storekeepers of storekeeper can also manage the transport and the transport changes can be deducted from either side (farmer or shopkeeper). Here, all farmers upload their crop output so that the system can determine the price of crops for the entire year based on the precise amount of crop output in a given area.

4. Result and Discussion

Digitization in agriculture is the process of enhancing and optimizing farming methods through the use of technologies like sensors, drones, and data analytics. The working of crop recognizing device used in our system are shown in figure 6 below.

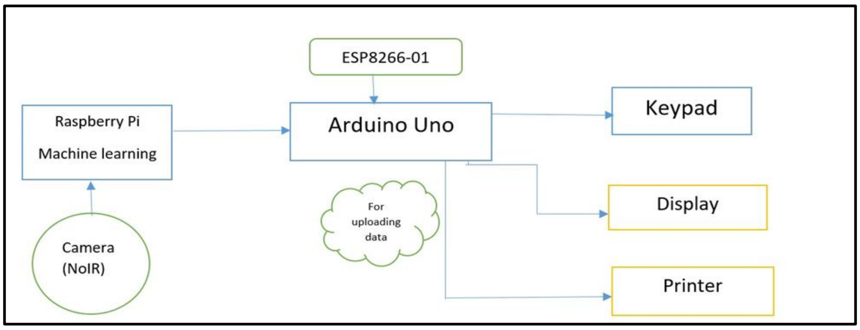

Figure6. Block diagram of crop recognizing device

This IoT-enabled device is designed for quality checks of crops and generates real-time receipts for farmers using AI techniques. In order to ensure the expected result, several major steps such as data collection, implementation, testing, and troubleshooting, need to be conducted. The prototype is built by combining the part of crop recognition and IoT together. This machine firstly scans the crop using the inbuilt camera (), and crop quality analysis is done as per the category. The details of the crops are shown in Table1.

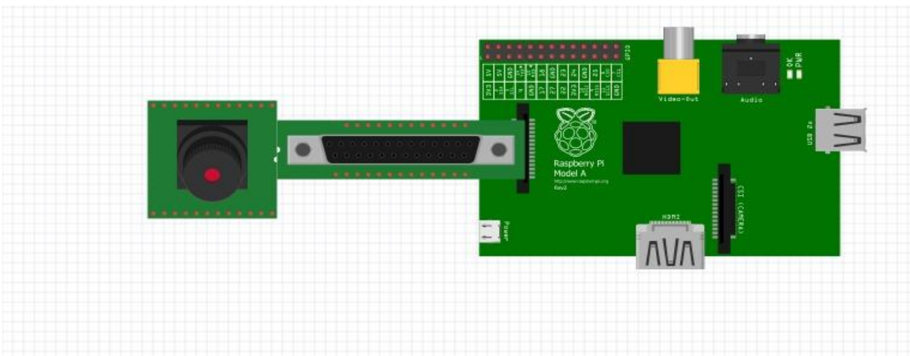

Figure7. IOT Enabled Crop Quality Check System

CURRENT DETAILS OF CROPS				
CROP ID	CROP NAME	1st	2nd	3rd
9	RICE	35.000	30.000	20.000
10	WHEAT	20.000	17.000	14.000
12	COTTON	300.000	260.000	210.000
13	GROUNDNUT	90.000	80.000	66.000
14	SOYBEAN	80.000	72.000	65.000
15	MUSTARD	50.000	45.000	38.000
16	MAIZE	20.000	17.000	15.000
17	BAJRA	35.000	32.000	25.000
18	URAD	90.000	82.000	71.000
21	PEAS	85.000	77.000	64.000
23	MMMM	1.000	1.000	1.000

Table 1. Details of Crops with their quality index

First Quality Second Quality Third Quality

Figure8. Quality of rice grain detected from IOT device

The quality and quantity of the crop are monitored by an on-ground agent. The above data is uploaded to the server for further processing taking place on the web portal. The real-time receipt is generated after successful verification of the above crop data and provided to the farmer. The buyer verification is done by an on-ground verification agent after submitting his records and token amount (minimum) for the receipt-generated amount. As a final step, the measured crop should be transported using the most economical transportation medium (suggested by the portal), to the buyer's place.

5. Conclusion

Digitization provides farmers with access to data and insights that can help them make better decisions and optimize their operations. By using data analytics and precision agriculture technologies, farmers can reduce waste, increase yields, and improve productivity on their farms. This is particularly important in the current economic climate, where profit margins are often slim. By gathering and analyzing data on their crops, farmers can make more informed decisions about when to plant, water, fertilize, and harvest their crops, potentially resulting in higher yields and higher-quality crops.

Digitization can also help farmers implement more environmentally friendly farming practices, such as reducing pesticide use and conserving soil and water. This can improve long-term agricultural productivity and environmental sustainability. Ultimately, the digitization of agriculture has the potential to revolutionize how farmers conduct business by providing them with access to data and insights that can guide their decisions, increase productivity, and enhance profitability.

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