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Revolutionizing Crop Monitoring: AI-Driven Machine Vision for Real-time Adaptive Harvesting and Loss Mitigation

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ABSTRACT

The research on implementing management strategies for crops that utilize the ESP32-CAM microcontroller to mitigate losses during the harvesting process. The capabilities of the ESP32-CAM in image processing and data transmission are utilized to construct a live monitoring system for agricultural fields. Using image analysis and machine learning algorithms, the system can identify the maturity of crops, the presence of pests, and the environmental conditions. It then provides practical advice to help make timely decisions about when to harvest. In addition, the ESP32-CAM serves as a tool for remote surveillance and management, enhancing the efficiency of farmers' activities and enabling the mitigation of losses during harvesting. The research highlights the integration of IoT technology with crop management techniques in contemporary precision agriculture, resulting in improved efficiency and sustainability of agricultural production.

Keywords: IoT; ESP32-CAM microcontroller; Real-time crop monitoring system; Vacuum pump.

1. Introduction

Through the utilization of the ESP32-CAM microcontroller's wireless and camera capabilities, we are able to acquire knowledge regarding and implement efficient crop management strategies, with the ultimate objective of minimizing harvest losses [1]. The ESP32 CAM is an excellent tool to use so that you can monitor a variety of environmental factors, including the ripeness of the crop, the health of the crop, and other environmental factors. Because of this, harvest planning and exploitation can be adjusted in real time to achieve optimal results. Through the incorporation of ESP32 CAM technology into crop management systems, the agricultural industry is able to reap the benefits of remote monitoring and control capabilities [2].

Farmers now have the ability to detect and treat a variety of issues, including diseases and pest infestations, with the assistance of this technology. After that, they are able to make use of the high-resolution feature of the camera to take photographs that contain a great deal of detail. These photographs can then be analyzed and possibly identifiable through the application of image processing algorithms. There are a number of factors to take into consideration, such as the stage of development, the phase of growth, and the readiness to perform harvest. By utilizing the ESP32 CAM in conjunction with various other environmental sensors, it is possible to monitor the moisture content, temperature, and humidity of the soil [3].

Because of this integration, farmers are able to obtain data in real time regarding the health of their crops, which enables them to make informed decisions regarding when and how much to water and fertilize their crops. The operator is able to acquire a precise representation of agricultural operations in real-time thanks to the feedback from ESP32 CAM sensors [4]. This information is then utilized effectively for the purposes of data analysis, decision-making, and real-time monitoring. Further, the Wi-Fi module of the ESP32 CAM makes it possible for farmers to receive timely notifications in the event that their crops are not performing well or if adverse weather conditions are on the horizon. Because they have this capability, they are able to take immediate preventative actions, which contribute to a reduction in losses.

To lessen the impact that shock has on plants, it is essential to install irrigation systems and make certain that they receive an adequate amount of water at the precise moment that they require it [5]. It is important to keep in mind that if there is an irrigation system already in place, you might need to adjust the amount while keeping the frequency the same. It is possible that it will not always be possible to provide water in its entirety. In light of this, it is of the utmost significance to provide the appropriate quantity of water at the appropriate time. Image analysis allows you to determine the best time to harvest each crop by analyzing factors such as color, size, and chemical composition [6]. This allows you to harvest each crop accordingly. A crop yield forecast that is generated with the help of sensor data would be beneficial to farmers in terms of assisting them in planning efficient harvesting operations. It is possible to reduce the amount of fuel consumed and the amount of damage done to the plant by using the data from the ESP32-CAM to plan the harvesting routes and machine movements in real time [7].

Increasing agricultural productivity and simplifying farm management procedures can be accomplished by integrating the ESP32-CAM with other devices and management systems that are part of an Internet of Things network. Develop a system that not only keeps farmers informed in a timely manner in the event that there are any issues with the harvesting process, but also makes it simple for them to access the ESP32-CAM feed from their mobile phones or other electronic devices. The adaptability of the system and its suitability for a variety of crop varieties, farming operations, and growing environments are essential components in ensuring the system's viability in a variety of agricultural settings. In the final step, you will need to save the photographs along with the data that was associated with them.

2. Related works

In recent years, there has been significant progress in the application of IoT (Internet of Things) sensors in agriculture, specifically in the utilization of devices like the ESP32-CAM. These systems have revolutionized the monitoring of crops in distant locations, enabling farmers to remotely evaluate the well-being of their crops, their growth progress, and the surrounding environmental conditions. The ability to detect problems early and effectively manage resources is crucial for contemporary agriculture, as it aims to optimize crop production while minimizing any potential losses [8]. Multiple research studies have investigated the utilization of Internet of Things (IoT) sensors in the field of agriculture, emphasizing their benefits in monitoring crops from a distance. The ESP32-CAM and other sensors enable farmers to gather real-time data on various parameters such as temperature, humidity, soil moisture, and crop health. By utilizing data, this approach allows for accurate and timely interventions, leading to enhanced practices in managing crops [9].

Researchers have employed image processing algorithms, specifically those found in cameras like the ESP32-CAM, to identify crop health problems, diseases, pests, and also to estimate crop yields. These algorithms often employ machine learning methods to automate analysis, leading to precise and dependable interpretations for farmers. Machine learning enhances the precision of these systems while simultaneously decreasing the requirement for manual examination and subjective evaluations [10]. The ESP32-CAM, apart from its image processing capabilities, has been integrated with a range of other sensors to create all-encompassing farm monitoring systems. By integrating the ESP32-CAM with temperature, humidity, and soil moisture sensors, a comprehensive monitoring network with multiple dimensions can be established. This integration empowers farmers to make well-informed decisions by providing them with a comprehensive understanding of crop and environmental conditions [11]. These systems have been proven to be efficient in practical situations. Field trials and case studies conducted on multiple farms have substantiated the feasibility and advantages of these integrated systems. These studies emphasize the potential to enhance crop management efficiency and reduce losses by implementing timely interventions.

Efficient data transmission between ESP32-CAM devices and central servers or cloud platforms is crucial for the success of these systems. Researchers focused their efforts on enhancing the existing wireless communication protocols to ensure precise and prompt transmission of data [12]. Dependable communication guarantees that farmers receive prompt information and alerts, enabling them to take proactive measures before issues worsen. Enhanced communication protocols facilitate the development of decision support systems using data gathered from ESP32-CAM devices. These systems offer farmers valuable insights and recommendations, enabling them to make well-informed management decisions. This technique not only enhances the efficiency of harvesting but also helps to prevent losses. Remote crop management systems utilizing ESP32-CAM have demonstrated efficacy in diverse practical applications. Real-time monitoring and early detection of issues provide farmers with advantages such as improved resource management and reduced losses [13]. Furthermore, these systems enhance the effective utilization of water and fertilizers by offering real-time data on environmental conditions. Nevertheless, there are challenges linked to the execution of these systems. Network coverage and data processing capabilities can constrain the scalability of IoT-based monitoring systems in expansive agricultural areas or multiple fields. In order for these systems to gain widespread acceptance, they must demonstrate resilience and dependability across a range of agricultural environments.

Conventional methods of monitoring crops often involve manual inspection and regular visits to the fields, which can be a waste of time and not very effective [14]. These methods heavily depend on subjective evaluations, leading to less than optimal decision-making. ESP32-CAM systems, on the other hand, offer objective data through image analysis and sensor readings, thereby minimizing the reliance on subjective judgments. Moreover, conventional techniques can impede the timely identification of crop issues such as pest invasions or diseases, resulting in substantial harm prior to their resolution [15]. The ESP32-CAM system's prompt detection and alert capabilities enable farmers to promptly intervene, thereby minimizing potential losses. Traditional resource management practices may also prove ineffective in addressing immediate environmental fluctuations. Without access to up-to-date information, farmers may encounter difficulties in efficiently managing resources such as water and fertilizers. The ESP32-CAM systems offer real-time alerts and notifications, allowing farmers to implement proactive and practical resource management strategies. The continuous advancement and enhancement of ESP32-CAM and other Internet of Things (IoT) sensors offer significant potential for the future of agriculture [16]. Researchers are continuously working to enhance the precision, dependability, and scalability of these systems. The effectiveness of remote crop monitoring will be enhanced through advancements in machine learning algorithms, wireless communication protocols, and sensor integration [17]. Moreover, the integration of these systems with larger agricultural management platforms can lead to a more comprehensive strategy for crop management. By integrating data from multiple sources, farmers can acquire a comprehensive understanding of their fields and make more informed decisions. Efforts are currently being made to enhance the accessibility and affordability of these technologies for farmers. Reducing the expenses of sensors and enhancing their user-friendliness will promote wider acceptance, particularly among farmers with limited resources and small-scale operations [18]. The application of Internet of Things (IoT) sensors in agriculture, such as the ESP32-CAM, has demonstrated significant potential in enhancing crop surveillance and administration. These systems offer up-to-the-minute information and advanced detection abilities, enabling farmers to make well-informed choices and reduce losses. Despite the presence of challenges, continuous research and development efforts are actively tackling these issues, leading to the advancement of more efficient and sustainable agricultural practices. The integration of cutting-edge technologies in agriculture serves not only to enhance productivity but also to guarantee food security and sustainability. As these technologies progress, they will have a growing significance in fulfilling the requirements of a swiftly evolving world.

3. Proposed system

Prior to beginning the process of harvesting time-loss crops, it is essential to first articulate the nature of the issue. When we talk about time-loss crops, we are referring to those that, if they are not harvested in a timely manner, have the potential to lose a significant amount of both quantity and quality. I would like to begin by providing a brief overview of the problem that was mentioned earlier, and then I would like to emphasize the proposed solution that effectively resolves the problem. The purpose of this is to provide a comprehensive explanation of the prominent characteristics of the system that has been highlighted, specifically queue scheduling, real-time monitoring, and speedy response, in a manner that makes it easier to determine the optimal timing for harvesting. In addition to providing information on recent technological advancements and the various approaches that have been utilized, you should also discuss the anticipated outcomes, which may include increased efficiency, decreased waste, or increased agricultural revenue opportunities.

For the purpose of addressing the problem of time-loss crops, which are crops that suffer from decreased quantity or quality if they are not brought to the market in a timely manner, the system that has been proposed is intended to be implemented. Finally, the choice to engage in a discussion about the solution is made because it emphasizes the effectiveness of the proposed solution in addressing this problem. For the purpose of ensuring that harvesting occurs at the appropriate time, please provide an explanation of the primary components and operational capabilities of the system. These capabilities include auto scheduling algorithms, integrated sensors, and SWIFT responsiveness. Examine the various technologies and methodologies, and conduct an analysis of the anticipated benefits that they will bring, such as increased agricultural productivity, decreased waste generation, and increased profitability for farmers. At the end of the day, it is recommended to provide clarification on the system's functionality and value proposition in the event that any questions are raised or if there is any feedback regarding the system. The first thing that needs to be done in order to get the process of collecting survey data on time-loss crops started is to introduce the ESP32 CAM system. One of the components of this system is a single-board microcontroller that is outfitted with both Wi-Fi capabilities and a camera component. The next step is to provide a clear and concise explanation of how the system operates: Image recognition algorithms that provide real-time, accurate harvesting timing based on geo-tagged conditions can be created by farmers using the ESP32 CAM. These algorithms can be generated by farmers. The advantages of successfully implementing this system should be emphasized. These advantages include the system's ability to grow in size, its affordability, and its suitability for use in areas with limited or remote infrastructure.

The ESP32 CAM is capable of capturing images of crops and analyzing them based on their primary indicators, such as color, size, and texture, in order to determine whether or not they are ready to be harvested. The ESP32 CAM is able to establish wireless connectivity with a central server or dashboard through the use of Wi-Fi. This enables farmers to remotely monitor the status of their crops and receive notifications regarding when they should harvest them. The system is able to collect and store data over an extended period of time. This capability is referred to as "data logging." In the future, farmers will be able to make use of this information to improve their crop management and optimize their harvesting strategies. The system is capable of being integrated with automated intake units, which will speed up the harvesting process without requiring any intervention from a human being. Because of its low cost and the ease with which it can be implemented, the ESP32 CAM is an excellent option for both small-scale farmers and large agricultural systems. The system that is being proposed provides a number of significant benefits, including the reduction of waste, the increase in profitability, and the improvement in efficiency.

3.1. Methodology

The essential hardware components include an ESP32 cam for video surveillance, an Arduino for data processing, a relay board for power supply management, and a vacuum pump for crop collection. Begin by designing an algorithm for Edge Impulse to monitor and detect the condition of your agriculture, after already choosing and obtaining the necessary hardware and software. This involves conducting data research and storing videos of crops and their environments, enabling the algorithm to learn how to identify various issues and conditions.

After the algorithm has undergone training, it needs to be integrated with the ESP32 cam in order to facilitate real-time operation and capture incoming video content. Program the ESP32 device to record video footage and process the data using a pre-trained machine learning model. Facilitate the establishment of communication between the ESP32 device and Arduino boards in order to transfer the acquired data from the ESP32. Ultimately, transmit instructions to the relay in order to manipulate the power. Verify that the data transfer between the ESP32 and Arduino microcontrollers is carried out accurately, encompassing the proper wiring and adherence to communication protocols. Establish a physical connection between the vacuum pump hardware and the Arduino human interface device to enable automated assistance. Initiate the operation of the vacuum pump upon the detection of mature crops by the machine learning model. After the collection has taken place, the container needs to be prepared to store the crops. Make sure that it is situated in a suitable position and readily accessible for transportation. Perform a thorough assessment of the entire system to confirm its correct operation.

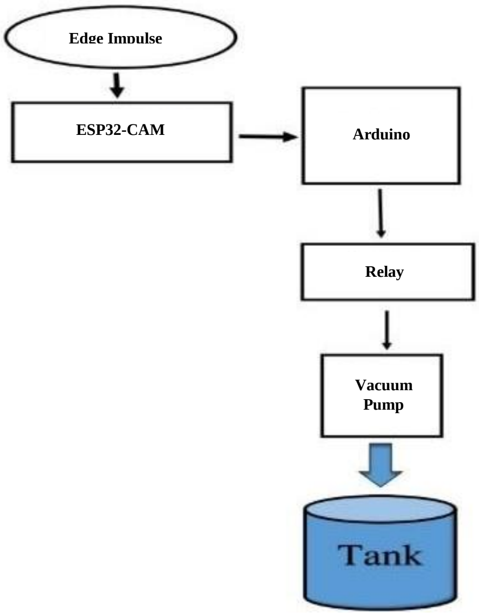

Figure 1. Proposed Block Diagram

If deemed necessary, perform meticulous modifications to the entire system. After meticulously fine-tuning the entire system to ensure optimal performance, the subsequent action involves implementing it for the specific task of monitoring and caring for crops. Edge Impulse is a specialized platform designed for edge machine learning projects. This means that it is specifically created to be utilized on compact devices such as microcontrollers or sensors. It is widely used in IoT applications that generate data at the edge and require time-sensitive processing. The Edge Impulse platform streamlines the four essential steps required to deploy machine learning models on edge devices with limited resources, facilitating various applications such as predictive use-cases, anomaly detection, and environment monitoring. The Development Board is built around the ESP32 microchip, which is a versatile chip that includes a built-in camera module. It is a widely favoured platform among developers who are focusing on IoT, home automation, surveillance systems, and similar fields. Through the use of WiFi and Bluetooth, this device has the capability to connect to networks and communicate with various devices. This makes it an ideal choice for a wide range of applications, including live streaming, image recognition, and remote monitoring.

Arduino is a commonly chosen platform, often paired with ESP32-CAM modules, for the purpose of programming and controlling various devices. The Arduino environment is designed to be user-friendly and comes with a wide range of pre-written code. This makes it easier to create projects using the ESP32-CAM microcontroller, which has built-in Wi-Fi and camera capabilities. Utilizing the ESP32-CAM, an Arduino-integrated device, enables you to capture images, stream video, communicate via Wi-Fi, and interact with other sensors/devices. This expands your capabilities in the realm of IoT, including home automation, surveillance, and more. The primary purpose of a relay is to control the supply of electricity to high-power devices, such as lights, appliances, or motors, by using a lower voltage signal to either turn them on or off. The Arduino is equipped with a gob switch system, which enables it to effectively manage devices that require higher power or operate at different voltage levels than the Arduino itself. A vacuum pump is a highly efficient device used for the purpose of extracting and collecting agricultural crops.

Farmers often utilize it to gather crops such as grains, fruits, or vegetables that have fallen during the in-field process, thereby minimizing waste and maximizing yield.

In 21st-century farming, technology is used to maximize productivity and reduce harvest losses. The ESP32-CAM, a flexible microcontroller with a built-in camera, is playing a crucial role in driving advancements in agriculture. This device is economically efficient, with recent advancements making it more affordable and simpler to handle compared to other sophisticated systems. Its minimal power consumption renders it well-suited for remote areas with sporadic access to electricity. The integration with IoT platforms enables farmers to monitor and receive alerts in real-time, facilitating improved planning. Additionally, its compact size and straightforward installation make it well-suited for extensive agricultural areas. Nevertheless, the ESP32-CAM is subject to certain limitations, such as diminished accuracy when performing intricate image processing tasks as a result of its constrained processing capacity and memory. Additionally, it depends on a consistent and reliable network connection, which can be difficult to maintain in remote locations. Moreover, it is vulnerable to environmental elements such as dust, moisture, and extreme temperatures, which can impact its performance and longevity. In addition, the limited range of the device necessitates the use of multiple units to cover large areas. Furthermore, there are security concerns regarding the transmission of data without adequate encryption and authentication mechanisms.

The software system for monitoring the cultivation of crops using the ESP32 CAM network and the Edge Impulse algorithm. This system is established to detect some conditions or happenings in the field which can be specific to crops health issues or the concerned with environmental factors, then the detected data will be shipped to the Arduino for further processing. Giving the conclusion that power management is the main part of the system that needs to be taken into account for the purpose of decrease power consumption. Moreover, along with a pump that collects dry materials from the harvest, you also describe using a vacuum pump. This indicates an optimistic take that will help us to avoid wastage and get the crops that may either fall, be lost, or may be stolen through capture during the harvesting process. The collected crops have been stored in a container, apparently for the next step that may be the processing or distribution.

4. Conclusion

In conclusion, the discussed system, integrating components such as the ESP32-CAM, Arduino, relay, and vacuum pump with the Edge Impulse algorithm, represents a significant advancement in agricultural technology. This collaborative setup enables efficient machine learning for real-time crop monitoring, crucial event detection, and loss minimization during harvest. By leveraging these technologies, the system embodies a proactive approach to farming, enhancing efficiency and improving yields. The integration of IoT and machine learning not only streamlines agricultural processes but also empowers farmers with timely data and actionable insights. As a result, this innovative system holds the potential to revolutionize modern farming practices, contributing to more sustainable and productive agriculture.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors took part in literature review, analysis and manuscript writing equally.

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