A Survey of Agriculture Applications Utilizing Raspberry Pi

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***Abstract*—Raspberry Pi is one of the most popular electronic prototyping boards used for prototyping the applications such as Home, Industry, Research, Agriculture etc. This paper provides a summary of Raspberry Pi adoption in agriculture to aid researchers in their work for remote sensing, controlling and automation. Soil quality testing, crop selection, soil fertility and productivity detection, weather monitoring, crop yield detection, plant growth monitoring and automatic spraying of fertilizers and pesticides are some of the Raspberry Pi applications which range from simple solutions to dedicated custom-built devices. The focus was mainly on different farming applications in which information is collected and processed to provide advice to farmers to make right decisions in right time with optimal expenditure. Research challenges, limitations and future trends associated with automated application development using Raspberry Pi are also presented.**

***Index Terms*—Raspberry Pi, Smart Agriculture, Smart Farming, IoT, Precision Agriculture, Weather Monitoring, Soil Monitoring, Crop Monitoring**

I. Introduction

Agriculture is an increasingly significant economic sector across the world as there is a constant and continuous growth in the global population. In order to feed the billions of people in the future, agriculture productivity of the world must be increased [1]. In order to increase yield and productivity, utilizing advanced technologies in agriculture will definitely help ultimately leading to the satisfaction of food demands of the world.

The advanced technologies help farmers to increase the crop yield by monitoring, controlling various aspects of crop production such as maintaining optimal weather and soil conditions and utilization of fertilizers and pesticides in right time and right amount [2]. Raspberry Pi is used to develop several automated sensing and monitoring systems for crop monitoring, disease detection, irrigation control, soil management and plant protection, etc. Fig. 1 depicts some of the applications of Raspberry Pi in Agriculture. Automated sensing and monitoring systems boost the yield of crops and minimize the expenses. These systems provide more related and accurate information in a timely manner for planting and growing crops. This article presents some of those systems developed using Raspberry Pi.

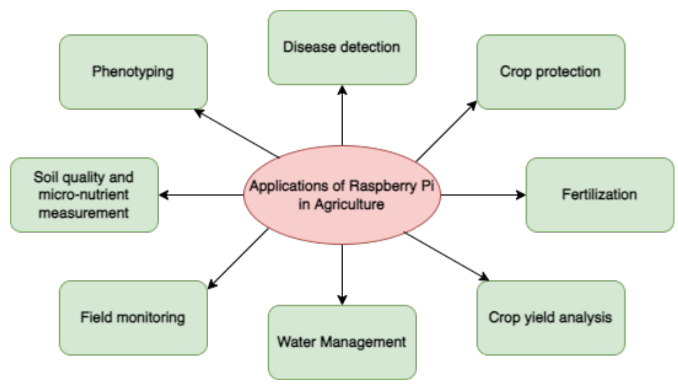

Fig. 1. Applications of Raspberry Pi in Agriculture

Section I consists of the introduces the use of Raspberry Pi in Agriculture. Smart agriculture and some of the potential applications of Raspberry Pi in smart agriculture are presented in section II. In section III, the advantages, challenges and limitations associated with developing the automated systems for agriculture using Raspberry Pi are discussed. Finally, Section IV presents the conclusive discussions and possible future applications.

II. Agriculture Applications

Raspberry Pi is being employed in several applications and is a prime candidate for hardware implementation for the past few years. It's powerful processor, rich I/O interfacing and compatibility enabled most designs to run on it. It is used in several applications such as Robotics, Biotechnology,

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Fig. 2. List of smart agriculture applications and parameters used

Home automation, Agriculture, Surveillance, Healthcare, Energy Management, Industrial applications etc. Among them, Raspberry Pi has been gaining traction in the field of Agriculture. Using various sensors and networking, traditional agricultural practices can be aided by these smart agricultural devices to achieve more yield improving the overall productivity. Fig. 2 depicts the list of parameters that can be sensed related to soil, plant, and weather and their applications.

A. Soil Quality and Micro-Nutrient Measurement

Soil nutrients enhance plant growth and agricultural output. Using several sensors, the quality of the soil and the presence of the nutrients can be examined, particularly to identify whether the land is suitable for agricultural farming or not. Maintaining adequate levels of macro and micro-nutrients in the soil is essential for production and sustainability in farms.

Fonacier et. al. [3] designed Soil pH and nutrient management device to calculate the amount of Nitrogen, Phosphorus, Potassium (NPK) and pH in the soil to determine the total amount of fertilizer to be used. This is necessary to improve soil fertility and quality as well as to reduce the unnecessary use of fertilizers, which will in turn increase agricultural productivity while providing the highest quality products.

Soil Quality Management System proposed by Madhura et. al. [4] sends real-time data to farmers on soil parameters such as Electrical Conductivity, pH, temperature, NPK content, and light intensity. The system also indicates suitable crop requirements and recommendations on fertilizer quantity.

Junfitrhana et.al. [5] proposed Potential Agriculture Land Detector utilizing Raspberry-Pi for detecting the state of the soil using multiple sensors to acquire ground altitude, air humidity, soil wetness and air temperature, using which the best plant to put in the field can be determined in order to boost agricultural productivity.

In [6], Kamath et. al. presented Precision Agriculture wherein Raspberry Pi is used to monitor the weed paddy plant's temperature, humidity, soil moisture level, nitrite content in the soil, and groundwater quality and report them to a remote station. Images have been processed to erase the background of the soil and different shape features have been detected. The paddy plant and weeds were divided using a random Forest section and a Vector machine support section based on the characteristics of the situation. This technique helps to improve agricultural production and to provide farmers with weed advice during the weed season.

B. Disease Detection

Plant health tracking and disease identification are both essential for farming. However, it is extremely difficult to manually monitor plant diseases. Therefore, researchers have come up with several devices to monitor health, detect diseases and to provide suitable solutions.

Gonzalez et. al. [7] developed a system that uses sensors and Deep Learning techniques where farmers can monitor and detect diseases in tomato plants. Also, this device informs about soil moisture, temperature, and humidity levels of the agricultural field to save effort and time by remotely monitoring tomato plants using image processing technology.

In Web Enabled Disease Detection System (WEDDS) by Nandhini et. al. [8], identification and classification of diseases on leaves using Raspberry Pi was performed. Camera catches leaves on a regular basis or whenever the colour of the leaf changes. Then, segmented image with the affected area is uploaded to cloud and experts suggest solutions to farmers based on these images.

Machine-based regression system using Raspberry Pi by Sarangdhar et. al. [9] was developed to diagnose and manage five cotton leaf diseases, as well as to monitor soil quality. It identifies and classifies five types of cotton leaves and displays soil parameter values such as humidity and temperature to the user. Using this information, water levels in the tank will be controlled and sprinkler system will be activated as needed.

Vhatkar et.al. [10] proposed a system to find infection index of apples from natural parameters and will send data to the server to predict pest infestation 7 days in advance, and information is disseminated to make pesticide spraying decisions.

C. Fertilization

Natural or chemical fertilizer elements are applied to soil or plant for supplying nutrients to improve growth and productiveness.

Automatic Fertilization System by Savani et. al. [11] customized the required five fertilizers to be added in the system as per the available database and shoved into the farm's water sprinkler system. Even farmers can modify the fertilization data using a touch screen device.

Arivalagan et. al. [12] developed Agricultural Robot for Automized Fertilizing with a web-camera mounted on it to monitor, analyze and detect soil moisture. Also, it measures the amount of rain using a rain sensor and sends a warning message to the farmer if there is too much rain. Hence, DC motor can be controlled using moisture sensor data to increase agricultural efficiency. Raspberry Pi with Passive Infrared (PIR) sensor is used to detect movement of pests and sprays fertilizer on the field to kill it.

Cultivation is to provide the right amount of soil nutrients and fertilizer to maximize a particular crop yield. Fonacier et. al. [3] designed Poly chromatic Color Sensor used to calculate the amount of NPK and pH in the soil sample. Color conversion potential of the soil will be compared with ideal values, then required amount of fertilizer to be used in the soil is determined and administered. This improves soil fertility, soil quality and reduces fertilizer use.

IoT based Fertilizer Intimation System was developed by Lavanya et. al. [13] that automatically informs the farmer about the pesticides to be used via SMS. The nutrients contained in three different soil samples are monitored and analysed using the NPK sensor, data is transferred to cloud to detect nutrient shortage. Based on this data, a message is sent to the user to inform about the amount of fertiliser to be used.

Muhammad et. al. [14] developed Tobacco Crop Agricultural Sprayer to differentiate tobacco and weeds by utilizing cameras and embedded with an agricultural precision sprayer. Crop/weed detection system with tractor-mounted boom sprayer find changes in scale, orientation, background clutter, outside lighting conditions and variation between tobacco or weeds and uses the sprayer accordingly for fertilization.

In [15], Ukaegbu et. al. developed a system that detects and sprays required amount of herbicides on weeds in fields using deep learning algorithms. These algorithms are programmed into an embedded system installed on a drone.

D. Crop Protection

Crop protection is a defensive strategy of crops against weeds, pests, viruses, plant diseases, and other potentially detrimental influences.

IoT based Smart Security and Monitoring Device developed by Baranwal et. al. [16] is used to notify the user and also to activate a repeller from a remote location, when rodents or insects are found in fields or grain store. When PIR sensor identifies heat, it activates URD sensor and webcam, sends information to the user.

Nanda et. al. [17] developed IoT-based smart Crop protection and irrigation system that monitors safety of the farm against animal attacks and the environment using open source and low-power gadgets. When PIR sensors detect motion within 10m range, camera will turn on capturing pictures and sending it to the IoT cloud. Meanwhile, based on temperature and humidity sensor's data, system emits a buzzer sound to alert the user. If there is a discrepancy in the predetermined threshold rate, an alert is sent and also updated on website for the farmer to take necessary action.

Giordano et. al. [18] proposed protection against animal attacks employing low power devices and open source systems to monitor weather conditions. When movement is detected by the PIR sensor, repeller will be activated to avoid animal invasions in the crop field. On the other hand, the monitoring system will gather weather data over a period of time as well as provide on demand notifications to the user.

E. Phenotyping

The phenotype of a plant is a term used to describe observable characteristics, such as height, biomass, leaf shape.

Tausen et. al. [19] proposed phenotyping system using a large number of static cameras, but the data created is huge. This system could simultaneously monitor 1,800 white clover (Trifolium repens) plants to measure plant growth, the rate of change of plant hue, or greenness, which could facilitate genetic mapping of plant's nitrogen status and fixation.

Susko et. al. [20] developed high throughput phenotyping systems used to measure a range of plant characteristics using detailed pictures captured in the field by an automatic camera system. Crop rotation, crop movement under field wind conditions, and identification aimed at new breeding to increase air resistance to crops such as wheat, oat, 2-row barley, and 6-row barley are also captured and sent to the user.

Tovar et. al. [21] developed a protocol that describes about image acquisition useful for quantifying plant diversity for high-throughput phenomic. Raspberry Pi computers and cameras are used to manage and gather plant picture data so that quantifiable plant attributes like shape, area, height, color can be extracted.

In [22], Dobrescu et. al. devised a phenotype technique for assessing rosettes' development rates and phenotypic features during the diel cycle. It analyses picture collections at the same time and properly segments and characterises numerous rosettes inside an image, independent of plant arrangement.

Minervini et. al. [23] developed image-based phenotyping using machine learning to count the number of leaves automatically from 2D photos and processed remotely on a workstation or through a cloud giving an analysis of morphology, growth, colour, or leaf count.

Bontpart et. al. [24] developed growth (rhizobox) and imaging system using five cameras that cover the entire farm surface to study root development in soil, frequently and non-destructively during the plant life cycle in order to estimate crop performance.

F. Yield Evalution

In agriculture, the yield is a measurement of the amount of a crop grown, or product harvested.

Automatic correction system using IoT by Tolentino et al. [25] is used to monitor plant growth. Some sensors are used to monitor the pH level and temperature of the system of the recirculating water. The system automatically triggered devices such as lights, fans, cooler, aerator, and peristaltic buffer device, if the acquired data was not within the threshold range.

Nasution et. al. [26] developed camera-based Chlorophyll meter using Raspberry pi to monitor chlorophyll content in leaves periodically. This is essential in maintaining the health of the plants and to diagnose diseases and fertilizer content which will impair the yield and quality of harvested rice.

Smart Harvest Analysis using Raspberry pi (SHARP) by Negi et. al. [27] predicts the agricultural yields, regulates water levels, irrigates, and analyzes farm forecasts. Motor control and monitoring can be from any device, including mobile phones, tablets, and PCs, to increase productivity by predicting the best possible yield. It also allows farmers to control SHARP manually or automatically making it easier for them to manage their irrigation system.

G. Smart Irrigation

Smart irrigation systems use advanced technology to improve the coverage and efficiency of their water conservation measures. They can also control the amount of water needed to maintain a certain area.

Hamdi et. al. [28] developed IoT-based sensors to monitor water levels and a message is sent to the user informing him about the water situation in his fields. With the help of this system, the user can get real-time environmental parameters via the sensor, which stores data in the cloud and can be remotely controlled using an Android application.

In [29], Benyezza et. al. uses a fuzzy logic controller (FLC) to collect all data and the data received is then sent via a wireless connection to a server (Raspberry Pi). This data is monitored to operate irrigation in greenhouse from anywhere and at any time.

In [30], Abioye et. al. uses discrete Lagurre networks in a predictive controller for precision irrigation minimizing water utilisation. Over the course of 21 days, the proposed technique can reduce water usage by 30%, while Laguerre functions reduce computational complexity.

III. Discussions

The concentration of mineral nutrients in soil plays a vital role in the growth and development of plants. Due to the difficulty of determining soil nutrients on a regular basis as it will take more time in laboratories, or doing it manually in agricultural fields, several techniques are reported to simplify this. Table I lists some of the state-of-the-art works proposed in the literature.

In [5], the proper plant species for the tested soil is displayed, as indicated by sensors, soil fertility, and farming location, and provides information about plants suited for planting in the tested soil. Sensors play an important role in real-time monitoring, however, deploying sensors underground

TABLE I
SUMMARY OF AGRICULTURE APPLICATIONS UTILIZING RASPBERRY PI

References	Applications	Sensing Parameters	Hardware used	Strengths	Limitations	Future Scope
[14], [11], [12], [13], [3]	Spraying pesticides/ weed detection	Soil, Plant, Weather Conditions in Farms	Raspberry Pi, Sensors, Sprayer, DC Motors	Measure the amount of NPK Values and provides the amount of fertilizer to be used. Customize pesticides requirements to be added in the system according to user requirements.	Sensors are also placed in a good location to work optimally. More accurate sensors are used for accurate results.	Extend by incorporating fuzzy logic-based control of the variable-rate precision sprayer in real-time and sprays on either crops or weeds, and also change flow rate according to the plant requirements
[5], [3], [4], [16], [31]	Soil quality/Nutrient monitoring	Temparature, pH, Conductivity, Dielectric, NPK Values	Raspberry Pi, color sensor, Air temperature sensor, Humidity sensor, soil moisture sensor, NPK Sensor	It works in real time. Analysis of the information collected and recommendations for the required plants are provided. Low-cost and easily scalable.	Sensors have many problems during communication such as distance, reliability, mobility, power considerations, capacity, processing.	Extend the current functionalities of the system and other devices can be added automatic watering and spraying pesticides-based on the requirements.
[6], [15], [30], [28], [27], [32]	Smart farm monitoring for yield improvement	Water level, light intensity, Air, Temperature, Humidity, pH, soil humidity	Raspberry Pi board, PIR Sensor, Soil Moisture sensor, Rainfall Sensor, DC Motor, Web camera	Farm conditions monitoring and DC motors is controlled by the Raspberry pi based on the input of the soil conditions for watering the farms. Command on the webpage, the respective DC motor will works.	Smart farm monitoring involves cloud. Cloud collaboration is a challenge in terms of cost, time and expertise.	Systems along with machine learning and neural networks will highly increase agricultural productivity.
[7], [8], [9], [29], [10]	Disease Detection in Crops	Soil moisture, Temparature, Humidity, Images , chlorophyll	Sensors, Camera, Raspberry Pi board, Mobile.	Detect and classify the diseases in leaves. Disease forecasting on the website. Remedies will be provided to the farmers.	Limited for few types of crops/leaves	Extended by adding modules to get notifications about diseases and appropriate precautions for prevention from experts for more leaves/plants.
[18], [17], [16]	Crop Protection	Attacks in fields by rodent/insects	PER, PIR Sensors, Rapberry Pi, Web Camera, Ultrasonic Sound Repeller.	Resisting and supervising system can be used to prevent farm damage from both wild animal assaults and weather factors.	Device's connectivity, data transmission, notification, and other factors such as PIR sensors will be affected.	Incorporate pattern recognition techniques for machine learning and to categorize them into humans, rodents and mammals.
[22], [21], [20], [19], [24]	Phenotyping	Plant growth, Falling, Shape, Colour of plants/leaf	Camera, Raspberry Pi, PC/Mobile	Measure plant growth, the rate of change of plant hue, or greenness, which could facilitate genetic mapping of plant's nitrogen status and fixation. Growth rates and phenotype characteristics of plants.	Network should be clear to update and process the photos of the objects.	Could be developed to operate the suitable amount of light intensity from the grown lights that can enable the plants to grow at maximum or optimum level in real time.

to reliably monitor soil quality is an economically challenging task.

In [4], farmers can get immediate results for important soil parameter conditions which are key for increasing yield and productivity. Systems can be expanded to automatic watering and pesticide spraying application based on sensor data after analysis. To achieve this, recommendations are made using the analyzed data on crops, fertilizers, and other features that can be used in the field to improve yields. Farmers get real-time test results for important soil factors like electrical conductivity, pH, temperature, NPK content, and light intensity, which are all important in increasing yield. The systems can be expanded to automate irrigation and fertilizer application based on the sensor data after the analysis. After analysing the data, it makes recommendations for crops, fertiliser, and other aspects that could be used in the field to improve crop yields [31].

In [27], sensors are used for Plant monitoring which drastically reduce human effort and can be further expanded by putting sensor data on the cloud allowing the user to access this data from anywhere. A reliable dynamic cloud collaboration is a big challenge in terms of cost, time, and discrepancy. Better yields can be obtained by using technology in agriculture such as increasing focus in deep learning algorithms for crop monitoring, employing machine learning models to track and assess various environmental impacts on crop yields etc,. Farmers must be able to afford such technology and it must be easy to maintain.

NPK sensor with its fuzzy rule-based system [13] allows the farmer to be automatically notified of the fertiliser to be used at the appropriate time through SMS. Most farmers are unable to implement IoT in agriculture due to lack of information, high acquisition costs, security concerns, Poor Internet Communication on Farms or Affected Cloud Communication.

In [32], environmental and soil sensors data about the crop is monitored and displayed on a regular basis by a server that is connected to the internet. Sensors have many problems during communication such as distance, reliability, mobility, etc. and resources such as power considerations, storage capacity, processing capacity, bandwidth availability, etc. are also a major challenge.

Various sensors collect data along with scanned image of plants, such data is examined to see if ailments are visible. Disease warnings will be sent to the user, if any. Disease detection in tomato leaves [7], a machine-learning based crop/weed detection system mounted on a tractor could perform site-specific spraying on tobacco leaves [14], WEDDS to determine and distinguish diseases in leaves [8], discernment and control of diseases on cotton leaf [9], plant disease forecasting in fields to the growth of disease and pests by interfacing sensors [10] are many such works reported in the literature to handle such challenges. Moreover, the camera used to capture the images must be accurate and the network used to analyse the data should be good. Disease testing is done only on a few plants / leaves, however, much work remains to be done on more plants / leaves.

In [3], poly-chromatic color sensor voltage values are compared to ideal soil's nitrogen, phosphorus, potassium, and pH values, and the appropriate amount of fertiliser is digitally displayed. High sensitivity sensors can be used to make it more efficient.

Autonomous fertilization system [11] enables the use of five different fertilizers to be added in the outgoing water supply that takes care of the fertilization requirements, which eliminates manual operation, optimizes irrigation and fertilization, and increases water usage along with the usage of fertilizer efficiently. However, it is only suitable for small farms.

Agricultural Robot for Fertilizing proposed in [12], wherein cultivation is carried out automatically without the use of manpower. Raspberry Pi is connected to a moisture and rainfall sensor, which controls the DC motor and sprays fertiliser on the field based on sensor data. It is an irrigation motor with motion control via a website without human interaction. A message has been issued to the farmer informing about impending extreme weather. An IoT-based Smart Security system [16], [17] detects rodents and crop risks and sends out real-time notifications based on data from PIR sensor after analysis and processing. A surveillance system is also presented in [18] to prevent potential damages to crops, both from wild animal assaults and weather conditions, which can be further expanded by adding a camera and the captured photos may be processed to take suitable action.

IV. Conclusion

Agriculture is a field of science where traditional practices have dominated the process for a long time. Smart agriculture is the need of the hour. With the advent of IoT and widespread use of internet and cloud technologies, the traditional agricultural practices can be combined with smart devices to automate certain or all processes involved. In this article, a comprehensive survey on recent agriculture applications that are implemented with Raspberry Pi hardware as the key module is presented. This article provides an extensive overview on current and continuing agricultural applications such as crop monitoring, disease detection, soil quality measurement, productivity boosting with fertilizers effected from universal Variables such as temperature, humidity, air pH, soil moisture, rain fall etc,. This review will be useful to agricultural researchers and embedded system developers in assessing existing methods and associated agricultural problems in order to develop more efficient and effective systems in the future.

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