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Applications of Wireless Sensor Networks and Object Detection in Precision Agriculture: A Review

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Abstract

Sri Lanka is a nation with a strong history of crop farming. For the vast majority of people back then, agriculture was the only profession accessible. The cultivation is declining because of the economic problems. By automating the agricultural process, a country's GDP and its residents' lifestyles will grow. The goal of this research is to learn more about the WSN-based systems that have already been created and to pinpoint the best technology and sensors for a WSN that will be created to support big farms in Sri Lanka. Wireless sensor networks in agriculture and other technologies utilized in agriculture as well as for object recognition were the two primary areas of focus of this study. This study comprises a systematic literature review which is conducted by reviewing the most important set of research papers after identifying 100 research activities related to the discussed field. Further, in this study, the proposed design for the system is also discussed. The ZigBee protocol, which is the most modern and most readily scalable protocol among the ones that are now available, was used in the development of the majority of WSNs. Sensors were employed to measure humidity, temperature, and light. Additionally, some systems had an inbuilt expert system to give farmers professional advice on crop cultivation. To take pictures of the field, cameras were placed in the sensor nodes. The Atmega128L, coupled with the ZigBee protocol and various sensors, is the controller of the node that this article finds to be the most appropriate. The most effective algorithm for object identification and categorization is DTE.

Keywords— **Wireless Sensor Network (WSN), Precision Agriculture, Image Processing**

I. INTRODUCTION

With the recovery of the Sri Lankan Economy in 2021, with respect to the accounts provided by the Department of Census and Statistics, the economy had a 3.7 percent growth as there was a contraction of 3.6 percent in 2020. The agricultural sector provided 2 percent of the growth of the economy. Plants need fertilizer, good sunlight, water, and other essentials for the good development of plants. The farmers need to monitor their cultivation constantly. By using a wireless sensor network, farmers can monitor the soil conditions, water level, and fertilizer needs.

Wireless Sensor Network (WSN) is a collection of nodes, which has the capability to capture the changes and the other parameters in the environment using sensors. A sensor node is a low battery-powered device that is capable of sensing the outside environment. It is also a very small and wireless device which can operate independently. The sensors can communicate with each other independently and process data inside the nodes. A WSN could monitor an agricultural system by controlling and changing different parameters. The parameters of temperature, humidity, and soil condition will be changed to keep the system in a controlled manner. The data gathered from a sensor network can be easily used to find out the status of the plantation or the agricultural field. In a WSN, different nodes can be deployed to perform several types of activities. Each single sensor node is comprised of five parts. They are microcontrollers, memory, analog to digital converters, sensors, and transceivers. The sensor network has the ability to process the data collected from the sensor nodes and to carry out active communication among the other nodes in the network.

Agriculture sustainability has a direct impact on the development of a country. Monitoring a large-scale agricultural field is not an easy task for a farmer. There are a lot of parameters and conditions that must be checked to have good cultivation. Monitoring includes several parts as data acquisition, transmission, and management. Not only wireless sensor networks, image processing techniques, and machine learning techniques can also be used for the monitoring and enhancement purposes of agriculture. Image processing techniques can be used to detect the amount of rainfall obtained for a geographical region and based on the results; the farmers have the freedom to decide on the type of crops they are planning to cultivate in their field.

Another issue that the farmers face is protection. In order to get good cultivation, it is necessary to protect the crops without any harm from both humans and animals. It is extremely hard to protect the crops from animals during both daytime and nighttime. Image processing techniques and machine learning will be used to overcome this issue. When automating the agriculture process, the farmers can embed cameras to detect suspicious activities in the area. Id image processing is used for animal detection purposes, Yolo Algorithm will be used for the image analysis. This research aims to find out the existing systems that have used WSN in the field of agriculture and provide the a most suitable approach to be used for a WSN-based agricultural system to be implemented in Sri Lanka.

As the outcome of this research, a solution will be provided on how to automate the agricultural process using a WSN. Some existing systems will be reviewed in order to find out inputs, outcomes, algorithms techniques, and accuracy. The best solution will be suggested by analyzing the literature.

The structure of the paper is as follows. Section 1 explains the research with a brief overview of the project. Section 2 describes already developed WSN-based agricultural systems. Section 3 explains the process of this research work. Section 4 contains the discussion on the finds and section 5 draws the conclusion for this research work.

II LITERATURE REVIEW

This section describes the ten most important papers reviewed when carrying out this research. This section is in two main parts, Wireless Sensor Networks in Agriculture and Other technologies in agricultural and non-agricultural fields. Factors like input methods, outcomes and accuracy of techniques are examined in this section.

A. Wireless Sensor Networks in Agriculture

Yi-Wei and Jiann-Liang [8] conducted research with the aim of solving the problem of the failure of communication and energy saving using LoRa as the protocol. LoRa technology has the ability to work for a long time without a battery replacement consuming very low battery. The authors found out that sensors cannot perform any computation. Therefore, as a solution for the problem, an intelligent platform for agriculture is developed. There are eight types of sensors used to monitor the surroundings in the proposed system and the best sensors are identified using two approaches, set sensors with the same feature at the same time and plot the data and analyze the differences and also by comparing the differences of a calibration sensor and a single sensor. The authors have identified eight sensing functions and grouped the sensors according to them. The authors have concluded that multi-sensor components with the communication network were established to collect data and control equipment.

Deepika and Rajapirian [4] conducted a survey and presented the findings regarding new and existing methods of WSN deployment. In WI-FI based WSNs, the complexity of collection of data manually from the agricultural field is reduced. The Bluetooth-based WSNs are better than WLAN because it is low cost, consumes very less power, frequency range is 2.4 GHz and is a short-range wireless communication. When considering Radio Frequency (RF) based systems, these systems are mainly used for greenhouse-based plantations. There are three basic techniques as, Frequency Hopping Spread Spectrum, Direct Sequence Spread Spectrum, and Diffuse Infrared [4]. ZigBee is the most recent protocol used in WSNs. The network is scalable and consumes only a lesser amount of power when ZigBee is used for the system. In the newly developed WSNs, cameras are also implemented to monitor the field easily and ZigBee is used in most of the systems. The data acquired are transmitted to the experts through the internet to get the expert solutions for the crops easily.it is concluded that in the new systems, FGPA is used instead of the microcontroller [4].

Hui, Nan, Zhao, and others [5] developed a system to monitor the plantation with the help of a WSN. micaZ [9] mote node was chosen as the based node of the proposed system. Atmega 128 was the proposed microcontroller because of the low power consumption. SHT10 is used as the temperature sensor and BH1750FVI as the light sensor. As the processing power of the microcontroller was insufficient, PC104 was used with the Linux operating system. IEEE 802.15.4 is used as the protocol of the proposed system. Wireless cameras are used in order to capture images of the environment. It is concluded that the system has the ability to monitor the field using video while monitoring environmental conditions. Cover and filter were implemented to minimize the effect of light intensity for the captured images.

Xufeng, Gang, Bin and others [10] developed a WSN based system to monitor the environment of the specific agricultural field. The proposed system consists of multiple sensor nodes which are wireless, several routing nodes, a central node and an SMS alert module working through GSM. the central nodes start the ZigBee network. The routing node is responsible for allowing other devices to enter the network and also performs multi-hop routing. The sensor nodes collect the respective environmental parameters which the system is monitoring. The main control part of the system was developed using Microsoft Visual C++ and MS Office Access. It is concluded that when the system is applied in real-time, the data is received with high accuracy and stability from the nodes.

Manijeh and Amene [11] carried out research on precision agriculture using WSN. The simulation tool called OPNET is used for the implementation of WSNs. The data will be called from the sensors in a multi-hop routing technique and the data will be then transferred to the sink node through the routing protocol. The authors propose two methodologies. In the first, each node will be deployed at the corner of the grid while the nodes are deployed randomly in the second topology. 4-hectare land with 24 nodes with WI-FI were used for both topologies. All the other parameters are also constant, and the best topology is determined using OPNET. It is stated that the throughput of the random topology is less than the grid. More packets will be delivered to the destination in the grid topology but the load is constant and coverage is 35% in random topology. The authors conclude that grid topology is the best because of the above stated results.

Ying Zhang [12] introduced the structure and the technology used for a node in the WSN. The communication protocol and the application method is proposed in this research. A node is comprised of a microcontroller, power supply, sensor, interface and IEEE 802.15.4 protocol. The Radio Frequency (RF) transceiver

is CC420 and the microcontroller is MSP430. The communication module is of two parts as bandwidth and RF. The selected sensors are, DS18B20 as temperature sensor, HIH3610 as humidity sensor and SFH206K as the Illumination intensity sensor. The communication protocol is ZigBee which consists of two layers called PHY and MAC. It is concluded that the proposed system is more advantageous than the present tradition ways as, the network can be set up easily, scalability, high flexibility and it is a low cost implementation when compared to the traditional system.

Aqeel, Abu, Noman and Zubair [13] carried out research with the aim of studying the necessity of sensors in field of agriculture, WSN technology along with their application in different areas of agriculture. The basic functions of a sensor network consist of sensing, communication, and carrying out computational activities. Out of ZigBee, Bluetooth, Wibree, and WIFI, the preferred communication protocol is ZigBee. The cost is low as well and the power consumption of the protocol is also very low. A sensor node is a collection of power supply, sensor, communication module, and processor. ATmega128L is the most used microcontroller because consumes only a less amount of power. The preferred operating system is TinyOS. Some of the agricultural uses of WSNs are irrigation, pest control, fertilization, greenhouses, and for the task of animal monitoring. It is concluded that WSN for a large system should have, Low costs sensor nodes, more generalized solutions for problems, and also a complete framework for decision support and modeling.

Shining, Jin and Zhigang [3] proposed a system to improve the growth of crops and monitoring using a WSN. The nodes are deployed in a farmland to capture real-time information. Then it will be updated to the computer or the mobile of the farmer. The farmer has the ability to monitor the farmland and can decide whether it is needed to water the farm or not. The authors state that the main requirements of the proposed system are monitoring the environment and controlling the field remotely. RISC-based Atmega128L with TinyOS is used as the microcontroller of the proposed system. AT86RF230 and AT45db041B were used as the RF Frequency chip and memory respectively. The sensor with less power consumption and high accuracy was selected. CTP protocol was used to collect the sensor data. The research is concluded by mentioning the characteristics of the developed node. They are low energy consumption, low energy wastage, and self-organizing ability.

B. Other technologies in agricultural and non-agricultural field

Jerome and Dominique [14] conducted research to find out the performance of Machine Learning (ML) algorithms for object detection in agriculture. The aim of this research work is to give a comparison of a methodology based on machine learning and a baseline used in agriculture and vineyards. The authors have found out the needs by the initial studies. The objective is to detect vine and their diseases using IR images captured by (UAVs) Unmanned Arial Vehicles. Out of several object classification methods, pixel-based classification (PBC) and object-oriented classifications (OOC) were reviewed and it is stated that OOC is the mostly used as it is based on nearest neighbor and rule-based classifier. Image analysis was carried out by the non-linear scale space filtering. The dataset used for this system, comprises of images from five vineyards in Switzerland. The images are divided in smaller tiles of 30x33 pixels and are categorized into three as, road, vineyard and other. 13,005 images [15] of the dataset were partitioned into two for training and testing. Two algorithms Baseline and DTE were used. It was justified that DTE (Decision Tree Ensemble) was the best as the accuracy was 94.275% and was stable in all iterations along with a stable accuracy. The authors conclude that DTE will be the most suitable algorithm as it is accurate and provide stable results.

Jeevitha and Vengatesh [16] proposed a system designed by deploying sensors which are wireless and it is capable of sending an alert message to the owner of the land and the officials of the forest along with the captured image of the animal. There is a sensor deployed for the detection of the animals and the camera is responsible for taking a photo of the detected animal. A microcontroller has been used for the classification of the image and the alert will be sent to the relevant personnel with the help of a GSM module. There are several layers in the proposed system. The topmost layer is responsible for taking the image of the animal when the signal is arrived at the microcontroller after the tasks of the sensor are done. At the next level, the captured photo of the animal will be forwarded for processing and finally, the image processing techniques are applied to the image. The authors have classified the detection system into three parts as, on-field which consists of sensors and cameras, the control unit and the GSM module along with the alerting system. The researchers have used three different sensors in order to detect the presence of animals and the sensors are, thermal sensor, Ultra Sonic Sensor and the Passive IR sensor. In the system, the authors will be storing some images of animals in there database, and of the captured image is similar to one of the images stored in the database, and SMS alert will be sent through the GSM module. The PIC microcontroller will be used as it can be easily integrated with Wi-Fi enabling it easy to perform communication tasks. Several hardware devices along with Python, Matlab, and Labview for image processing will be needed to make the complete system. Even though there are some drawbacks to using IoT in agriculture, they can be overcome by deploying batteries with solar energy, scaling the sensor network, and using developed technologies. The deployment of a camera is one

of the biggest operations of image processing techniques in terms of live video.

After reviewing the most related set of research activities, it is identified that even though the researchers have conducted research on this field, there is no physical system built up to address the identified problems. As a result of this literature survey, the authors will be proposing the most appropriate device to overcome the identified issues.

III. METHODOLOGY

To select the most suitable approach to be used for an automated agricultural system using WSN and to find out the most suitable technology to be used to detect and monitor the animals entering the farm. The main problem faced by farmers in Sri Lanka is the difficulty of monitoring the crops during the daytime as well as nighttime. Controlling animal attacks is also a challenging task. The solution identified for the problem is to implement a WSN. A WSN can detect environmental factors by using the sensor nodes. Then the detected values will be passed to the central control system and the farmers will be able to monitor the field from anywhere they are. This chapter is about how this systematic literature review is carried out to analyze the technologies and other factors used in similar systems to implement the most accurate and cost-effective WSN for agricultural farms. This literature review will provide the most suitable approach and technologies for the WSN. Figure 1 represents a graphical representation of the methodology of this research.

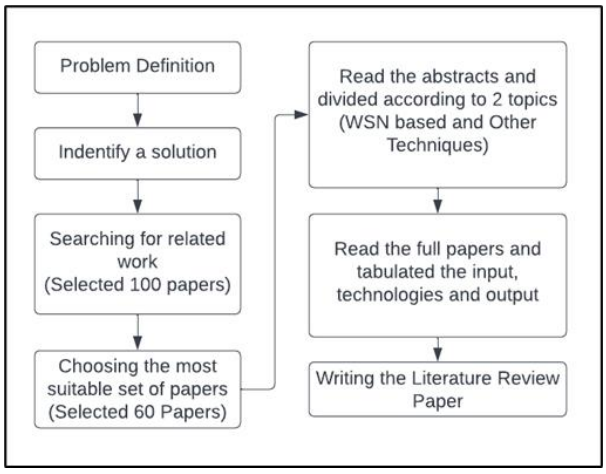

Figure 1. Methodology of the Research

Some farmers were contacted for the initial site observation. Factors like the current issues facing, the current methods farmers use to monitor crops, the time they must spend checking the field and their preference, and the opinion regarding the proposed automated method considered for initial investigations. Then the problem was defined. Then the solution was identified. In the initial process of this research, 100 research papers which are related to precision agriculture were selected. Sources like Google Scholar [17], IEEE [18], Academia.edu [19], and Springer [20] were used to find out the related research work. When selecting the research papers, the highly cited papers were given priority. Google Scholar was used to search for the papers. One set of papers was selected under the topic 'Agriculture and Wireless Sensor Networks.' Another set was under the topic 'Agriculture and Machine Learning' and the final set of research papers was based on the topic Agriculture and Image Processing'. The other part of this study is to find out about the object detection mechanisms available. Another set of papers with similar existing non-agriculture-based systems was selected.

From the 100 research papers, the most suitable set of research papers was selected by going through the abstracts. 60 papers were identified as the most suitable set of existing works to be reviewed for this research. Abstract, citations, date of publication, and reviewer comments were considered when selecting the 60 papers. The abstracts were referred to select the set of 60 papers. The highest priority was given to the papers with the highest relevance to the proposed solution and also to the papers that clearly mention the main components of a WSN.

From the selected 60 papers, the abstracts, and discussions of each paper were read and ordered into two main groups, 'Agriculture and Wireless Sensor Networks' and 'Other Technologies'. Accuracy, outcomes, number of citations, and date of publication were considered when selecting the final set of papers. There were 15 papers in the selected set. Most of the papers were related to agriculturally based WSNs and the other papers were agriculture and image processing. Non-agricultural related papers were also selected to study object detection and tracking processes.

After selecting the final 15 research papers, the full research paper was read, and the important points were highlighted. The reference manager 'Zotero' [21] was used in this task. Each paper related to agriculture was reviewed critically and data like the types of sensors, protocol used, network, sensed environmental parameters, decision-making strategy, and the technology used were tabulated. From the set of non-agricultural papers, the object detection mechanism, the algorithm used, and the techniques used were also extracted and tabulated.

Once all the papers were reviewed critically, the preparation of the literature review paper commenced. 10 papers out of the 15 papers were selected to write Section II which is called the 'Literature Review'. The literature review is organized as follows; the section was divided into two main subtopics 'Agriculture and WSN' and 'Object detection techniques in agricultural applications.' Each section is organized according to the year of publication of the research work. The most recent papers are at the top and the other papers will be arranged accordingly. The main technologies and other features extracted by reviewing the final set of papers are included in the literature review section.

Out of the papers related to agriculture and WSN, the types of sensors, the technology, the used protocol, and the environmental factors considered were compared and the best approach was identified. From the research work related to object detection, the types of cameras, the algorithms used, and the techniques were compared and the best process of detecting animals was also identified.

IV. DISCUSSION

This section includes a summary regarding the types of sensors, protocols, specifications of nodes, and also the image processing techniques and algorithms used in object detection and monitoring. Table 1 gives the main technologies identified by reviewing the selected papers mentioned in the literature review. Each paper was reviewed accordingly to finally identify the most appropriate technology.

Table 1. Summary of the Literature Review

Paper	Main Area	Main Components	Other Components	Important Facts
	WSN	LoRa Environmental sensors	Arduino	Actual measurements were made and 8 best sensors were identified. Sensor house was established for the protection of sensors from different threats.
	WSN	Field Programmable Gate Arrays (FPGA)	WSN802G modules WPA2-PSK protocol SHT15 TAOS TSL2561 sensors	FGPA is used as the microcontroller ZigBee-based WSN will be the best as it is scalable and consumes only less amount of power.
	WSN	MicaZ nodes TinyOS	Atmega 128 CC2420 PC104- processor	The workers are capable of controlling IP cameras remotely. Micaz mote nodes are selected because of low power consumption. PC104 is used along with Atmges 128 as it was unable to meet the processing needs.
	Heterogeneous Wireless Networks	OPNET Zigbee	Mesh topology is used for the routing and acquisition tasks Coordinator node, Routing node, Sensor node	The real-time data obtained by the system was highly accurate and stable.
	WSN	Grid Topology (Each sensor node is placed at the corner of each grid) Random Topology (Each sensor node is placed at random positions)	OPNET	The throughput of random topology is less than the throughput of grid topology. More packets can be delivered to the destination using grid topology compared to the random topology
	WSN	MEMS technology	IEEE802.15.4/ZigBee CC2420 Wireless transceiver module	WSNs are low-cost, highly accurate, and flexible methods when compared to the traditional agricultural process.
	WSN	Zigbee,	Sensor, processor, power module, and the communication module RF transceivers of model CC1000 ATmega128L microcontroller ISM band Embedded sensors	WSNs for large systems should comprise low-cost sensor nodes and a proper framework for modelling and decision support.
	WSN	MEMS technology	8-bit High-performance microcontroller Atmega128L CTP protocol	The sensor nodes should have the ability to organize by themselves, and should consume low power as well as less energy.
	Machine Learning, DTE, Baseline	Object-oriented Classification Pixel-based Classification	Unmanned Aerial Vehicle Baseline Decision Tree Ensemble (DTE)	The accuracy of DTE is 94.27% while Baseline was accurate only for about 90.07%. It is proposed that DTE is the most accurate with a very small amount of misclassification.
	Image Processing	Image Processing techniques (Segmentation, Feature Extraction, Classification)	Thermal sensor Ultra-Sonic Sensor Passive IR sensor	Live video is obtained by the deployment of cameras which is one of the main image processing techniques.

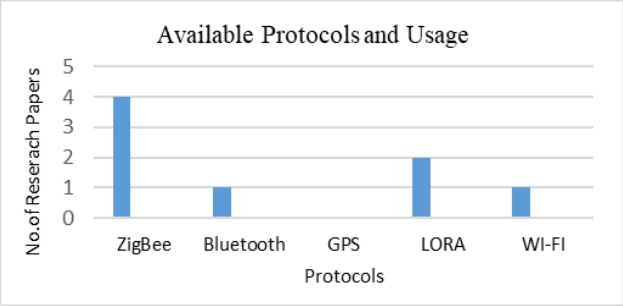

Figure 2. Usage of Communication Protocols

From the set of the reviewed papers, the following features were observed. The WSN-based agricultural research used sensors to detect the environmental changes like temperature humidity and soil. There are several communication protocols available to carry out the communication tasks. ZigBee, Bluetooth, GPS, LORA and WI-FI were the protocols used in the system developed. Out of the protocols, Zigbee is the protocol used by most of the researchers. Hui and others used SHT10 as temperature sensor and BH1750FVI as the light sensor [5].

The sensor node has a transceiver and CC1000 RF transceiver was used as the transceiver in most of the models [13]. Most of the systems used TinyOS along with the RISC-based microcontroller as it is low cost and consumes a very small amount of battery.

In the papers related to the other set of technologies, machine learning was used for object detection. The baseline algorithm and the DTE algorithm were the two algorithms used for the object detection purpose. The other technique used was the detection of animals entering the agricultural field. For that, an image is captured and the captured image is analyzed by image processing techniques. An SMS message was sent through the GSM module to the farmer notifying them that an animal was observed [16].

After analyzing the results obtained, the authors state that the most suitable ML technology to be used for animal Detection is CNN and VGG-16 can be used as the base model to train the initial model. The raspberry pi Fishe Eye cameras and a GSM module will be the most appropriate to be used for the IoT device.

V. PROPOSED DESIGN

After completion of the systematic literature review, the following design is proposed and the implementation of the proposed system is in process. Figure 2 depicts the proposed hardware design of the system.

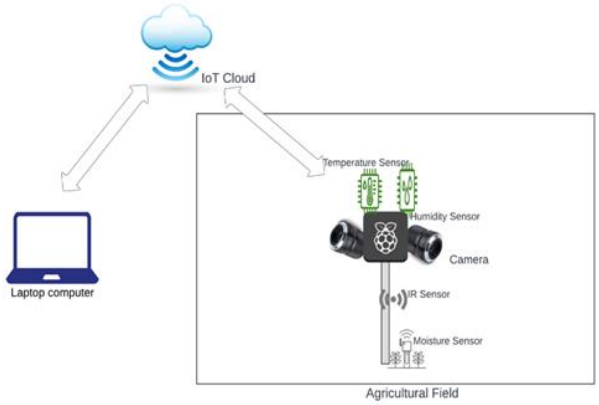

Figure 3. Proposed Design

In the proposed system, there will be two main components. Namely, the IoT device and the Machine Learning model which is used for object detection and classification. The implementation of these two components will be carried out in parallel. As initial development, the machine learning model will be developed with the use of Convolutional Neural Networks. Then the model will be tested and steps will be taken to improve the accuracy of the developed model.

In the IoT device, there will be a Raspberry Pi 4 Model B board and the sensors will be connected to the Raspberry Pi. The temperature sensor and the humidity sensor will be connected directly to the Raspberry Pi. The device will be implemented in a board that is connected by a stick. The PIR sensor will be set on the stick and then it will be connected to the Raspberry Pi with the help of cables. The two cameras that are used to detect animals will also be connected to the Raspberry Pi directly. If a living object is detected, the cameras will be activated. Then the objects will be captured in real time.

The data which are gathered by the sensors and the cameras will be sent to the IoT cloud and then the data will be updated in the dashboard which is in a form of a website. Further, this system is capable of sending an alert message if any object is detected from the field.

By implementing the proposed system, the farmers will be able to save the harvest from wild animals in an easy manner as well as they will be able to monitor the status of their cultivation remotely. The limitations of the proposed system is that the device will be operated using batter power and battery replacing must be done in a timely manner and also, sometimes, there might be instances where the device will not properly detect the animals as the environmental conditions might not be well suited for the camera module.

VI. CONCLUSION

The selected papers were divided into two main topics when reviewing. The two topics are, ‘wireless sensor networks in agriculture’ and ‘other technologies related to agriculture and object

From the papers related for the field of agriculture, only one system was developed using a FGPA instead of the microcontroller [4]. ATmega128 was not sufficient to process the collected data. An addition PC called PC104 was used [5]. RISC based Atmega128L was the recommended processor for the WSN [13]. Deepika and Rajapirian recommend ZigBee protocol as the communication protocol because it is a scalable and a low-power consumed protocol [4]. Xufengan and others proposed a system which is capable of sending a SMS alert to the farmer [10]. Some of the systems are capable of providing expert instructions according to the data received through the sensors.

From the set of non-WSN based papers reviewed Jerome and others propose that DTE is the most accurate algorithm because it provides stable results in all the iterations of object detection and classification compared with Baseline algorithm [14].

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