Abstract— In developing countries, crop production has declined due to inefficient agricultural and irrigation practices. Due to certain social and economic constraints, rural producers are reluctant to adopt efficient technologies that can help them obtain better yield. To increase the acceptance of technology in agriculture, we need a simple, cost-effective and reliable system that can help manage the farm based upon the critical parameters necessary to improve crop growth. This paper provides an introduction to an economical Wireless Sensor Network-based solution for precision agriculture that can help farmers to monitor their farms remotely. Our research examines the feasibility of implementing this proposed system in developing countries. Moreover, this paper gives an overview of our analysis for implementing our prototype using different wireless technologies that could be used to improvise the performance of the precision agriculture system.

Keywords—Wireless Sensor Network, Precision Agriculture, Field Conditions, GSM, GPS, Sensor Nodes

I. INTRODUCTION

Agriculture is the backbone of many developing countries, where about two-thirds of the population depends on it for economic sustainability. The 2011 Census shows that approximately 70 percent of the Indian population is engaged in agricultural practices [1]. However, the agricultural yield has always been below par due to conservative and inefficient practices of irrigation, fertilization and cultivation resulting in large economic losses.

Thus, there is a need for an efficient system that keeps track of the farms at every point of the cultivation process using real-time monitoring and taking corrective measures at the time when anomalies are observed. The use of technology in agriculture helps ensure that farmers obtain the best possible yield. Innovation and technology need to be introduced in the fields to achieve optimal crop cultivation yields.

II. RESEARCH QUESTION AND PROBLEM SETTING

A. Research Question

Can a reliable, easy-to-use and cost-effective system be created for precision agriculture monitoring using wireless sensor networks?

B. Problem Setting

Figure 1 below shows a graphical representation of India’s crop production versus the population at different points in time.

It is evident from the above graph that the crop yield does not keep pace with population growth. Thus there is a demand for a more efficient agricultural system. Farmers in rural regions often struggle to meet the high demand of crop supply due to a lack of sophisticated crop...
cultivation techniques. The scarcity of modern agricultural monitoring technologies leads to poor crop productivity and financial losses.

There are several factors which govern the adoption of a new technology. In countries like India, technology adoption can be slow due to initial implementation costs and resistance on the part of farmers. Barriers to the adoption of technology in agriculture can also be in part due to traditional belief systems, peer pressure from other farmers, habit, community expectations, etc.

Once this issue is addressed, implementing a comprehensive agricultural management system in an underdeveloped area raises concerns such as scarcity of energy resources, insufficient funding and lack of technologically skilled manpower. Three main design criteria have to be considered to address the aforementioned concerns. These criteria are self-sustainability, precision and cost-efficiency [2].

First, the system should be self-sustainable in order to minimize the necessity for human intervention in control activities. Secondly, the sensor monitoring system should be accurate in its measurements to facilitate precision in the control process. Precision in control decisions is necessary to maintain a healthy crop and yield greater productivity [2]. Third, the system should make use of technology that is both affordable and efficient at the same time. This criterion plays an important role in a rural setting as it helps in promoting widespread adoption of the system. The proposed system has to meet all three criteria stated in order to be suitable for rural crop cultivation.

III. RESEARCH SUB-PROBLEMS

Based upon the problems that are addressed in this paper, there are three main sub-problems.

A. Barriers that prevent new technologies from reaching the farmers in rural areas/reluctance to accept new farming methods.

As discussed, these barriers can be due to traditional belief systems, peer pressure from other farmers, habit or community expectations. This would gradually change with a greater number of farmers adopting the proposed system.

B. What can be done to improve the spread of new technologies?

In Peru, over 1000 video programs on agricultural and livestock production were distributed to farmers, the majority of which were illiterate [3]. The course utilized existing farming knowledge merged with new technology. In a survey, 92 percent of the farmers applauded this approach because it was similar to being on the field [3]. Since such a program was successful in Peru, other similar agricultural countries can follow suit in encouraging farmers to accept and use technology in agriculture.

C. Choosing an energy efficient wireless communication protocol that can facilitate information exchange between the controller and the sensor nodes.

This sub-problem elaborates on the need of an energy efficient communication protocol. Since the main goal of this research is to design a system for rural implementations, it should have low power utilization and reduced maintenance. Such a low power, low maintenance system can be designed using a communication protocol that exerts less processing overhead on the controller as well as the sensors, thereby increasing the battery life of the devices and reducing the need for maintenance.

A possible solution for this sub-problem is the IEEE standard 802.15.5, a communication protocol applicable for wireless mesh networks. Specifically, this paper proposes to analyze the low rate WPAN mesh routing standard defined by IEEE 802.15.5 in order to determine the feasibility of using it in the proposed system for rural area deployment. The energy saving mode supported by the low rate WPAN mesh standard may prove ideal for deployment in fields with fewer sources of energy [4].

D. Ensuring the adaptability of the proposed system as per the spectrum constraints imposed by its geographical location.

This sub-problem focusses on the operational limitations imposed on the proposed system due to the regulatory policies governing the wireless spectrum within the region of deployment. It is therefore necessary to develop a system that avoids problems with inconsistent regulatory spectrum policies between countries.

A possible solution for this sub-problem is to study and analyze the applicable policy specifications in every geographical region of operation. Based on the study results, a comprehensive list of possible operational challenges could be identified. These operational constraints could then be addressed either by obtaining appropriate regulatory approvals or by designing workarounds to ensure effective operation of the system.

E. Examining and analyzing the feasibility of building a precision agriculture system

This sub-problem centers on scalability of the proposed system and its support for future improvements
in crop cultivation practices. It is necessary for any research project to anticipate future developments and implement a scalable design. With the above goal in mind, this section focuses on the challenges associated with building a precision agriculture system that scales well to support multi-crop cultivation.

IV. LITERATURE REVIEW

Precision Agriculture (PA) is an agricultural system which is designed to improve the agricultural practices and processes implemented in order to maximize the productivity of farms. The idea behind precision agriculture is to monitor every step taken in farming. This system is information-based and technology-driven [5]. Continuous real-time monitoring of environmental and physical parameters, including soil moisture, temperature, humidity and soil fertility is provided. PA provides the benefit of obtaining and providing real-time feedback on the crops and environmental conditions [5]. Precision agriculture also involves keeping an account of the irrigation and fertilization of the fields to ensure that the amount of water, pesticides and fertilizers are provided as required and there is no unnecessary waste of these resources.

Wireless Sensor Networks (WSN) are networks of small sensors (also called motes) deployed across a certain area which communicate with each other using the wireless medium. These sensors are low-power, low-cost devices that comprise of sensing, data processing and wireless communication capabilities [5]. Figure 2 gives a brief overview of the components that make up the WSN node.

![Fig. 2. WSN Node Block Diagram [5]](image)

As seen in the given figure, each node has a processor that may have different kinds of memory, a power source, a communication module (RF transceivers) and sensors.

Effective deployment and support for multiple sensors to obtain the parameters critical for better crop cultivation has resulted in increasing demand for WSN. WSNs are becoming an ideal solution for providing effective and economical solutions for monitoring issues. This is because of its advantage over wired networks where it is feasible to install wireless access points at locations where cabling is almost impossible, and it also reduces infrastructure costs [5]. Kassim, Mohamed Rawidean Mohd, Ibrhim Mat, and Ahmad Nizar Harun say that using wireless technology would eliminate about 20-80% of the wiring costs in infrastructure installations [5]. WSN is being used in applications like health, environment monitoring, precision agriculture and vehicle tracking. Figure 3 depicts an example of a WSN.

![Fig. 3. Example of a Wireless Sensor Network, [6]](image)

Sensors in such networks are generally deployed in a dense fashion to ensure effective coverage of the entire area. They are also placed in close proximity. This proximity ensures that the information can traverse across the network until the end point, which could be considered as the base station. The best part of a WSN is that even if a node fails, the network can converge on its own. Based on the role in the network, nodes are classified as a cluster head, that collect the data from other nodes in the cluster and sends this information to the base station, sink nodes, and active nodes. Sink nodes are back up cluster nodes that become activated when the cluster head goes down. Active nodes collect the data continuously and keep transmitting them to the base station [7].

In [8], J. Jao et al have introduced a prototype created using WSN to collect soil moisture content that considers the issue of limited power supply, by making use of solar panels and rechargeable battery. This prototype was designed to collect data of soil moisture from different types of soil using MicaZ motes along with the MDA300CA data acquisition board and EC-5 soil moisture probes, along with TinyOS 2.1.1 acting as software. The data obtained from the measurements is sent to the base station using networking protocols.

In [9], Murakami et al present a system, called iFarm, which was created to support farm management. This system is a cultivation management system which comprises of smartphone applications that help in information collection, a web browser and a cloud server that helps the farmers share their collected data and access from anywhere. This system helps farmers to put in their schedule and important data as records into the system, which can be used for analysis of farming costs and help them provide an effective work plan for their farms. To reduce the running costs for the system, Wi-Fi was used for smartphones to communicate with the Cloud Server.
H. Ochiai et al present the idea of implementation of delay-disruption tolerant networking (DTN) [10]. DTN uses the major factor of mobility of the tractors and farmers if the sensor nodes in the WSN are sparsely deployed across the farm, to improve farm coverage. The mobile elements in a farm are deployed with short-range communication devices that help to obtain the data and store in the server. These mobile elements which have the communication devices mounted on them collect all the farm-related information like soil moisture, temperature, humidity and so on. All the communication devices together tend to form an ad-hoc network to find each other and communicate with each other, providing all the information collected by them from the sensor motes deployed across the farm. The concept of Potential-Based Routing (PBR) is also applied here for obtaining autonomous data transfer from the sensor nodes to the data server.

V. RESEARCH DESIGN AND METHODOLOGY

This section aims to specify design methodologies to address each of the concerns raised by the sub-problems mentioned in the “Research Sub-problems” of this paper. Additionally, a design plan and setup is discussed for each sub-problem.

The first sub-problem, the barriers for new technologies to receive acceptance from farmers, could be due to various reasons like financial difficulty to purchase the system that is unaffordable for them and superstitions that sometimes prevent the villagers from using such systems. For example, some money-lenders influence illiterate farmers and warn against using sensor systems in order to ensure the well-being of their business.

The second sub-problem concerns the methodology needed to ensure widespread promotion of the system by farmers even after overcoming those barriers.

Some of the possible solutions that could be implemented to solve these two problems in conjunction are: distributing easy-to-use user guides made in various regional languages, providing interactive videos in regional languages and seminars in different regions. We could encourage the use of this system by initially providing the systems for free and evaluating its performance. We could also provide cold storage facilities for their produce in the early stages of using the proposed system. Such incentives would definitely catch the eye of farmers and help in breaking the barrier created around them that prevented their adoption of such technology.

Another way to help people become aware of this technology is by introducing it in agricultural universities, which can be a good way to obtain infrastructure for further research and development in this area. The system should also be automated as much as possible for the farmers to have minimal work to do when the systems are deployed.

Automation of the system would help even the ones who are not skilled enough with technologies. The system could just be made like a plug-and-play device, where the system is enabled by the farmer and all the work is done by the sensors that would report the values collected from the farm on a periodic basis and by the system to take appropriate actions automatically for any anomalies reported by the sensors. Such a system would be widely accepted in the market.

The third sub-problem deals with choosing an energy efficient wireless communication protocol that can facilitate information exchange between the controller and the sensor nodes. The wireless medium chosen for deployment depends on the scale of the network, power requirements and the cost. Different wireless technologies like Bluetooth, LTE-Unlicensed, Zig-bee and Wi-Fi come to the mind.

If the distance between the farm and the monitoring station is small, Bluetooth technology is a good option for adoption because of its advantages of being power and cost-efficient [11]. Cellular communication technology can also be used if the distance is in the range of kilometers. However, power requirements and the cost of cellular communication is higher than that of Bluetooth [11]. Zig-Bee could be used as it is very efficient in terms of cost and power if the distance is in the intermediate range of a few hundred meters [11].

Further, new technologies like Wi-Fi can be explored if the distance is only a few feet. Since, Wi-Fi operates in the unlicensed band, it is better than other technologies because of the absence of scheduling mechanisms [11]. Also, considering the fact that rural areas do not use often use Wi-Fi, the unlicensed bands will not have much interference and contention to the medium. Therefore, the alert signal does not have to contend for the medium.

Another option could be the use of LTE Unlicensed for longer distances. This option is viable if regulatory bodies allow the use of this technology for this purpose. This is an expensive option because of the sophistication of the devices used in technology, but it consumes less power and, since it operates in the unlicensed band, it is much easier to operate.

The fourth sub-problem deals with ensuring the adaptability of the proposed system as per spectrum constraints imposed by its geographical location. One feasible solution to this sub problem is to build a technology agnostic system. Different countries have different policies regarding the use of the wireless spectrum. Therefore, the system should not be dependent on a single wireless medium and should work as expected on any underlying wireless medium like Cellular, Wi-Fi, Zig-Bee, LTE-U or Bluetooth whichever fits the needs of the application.

Finally, the last sub problem deals with examining and analyzing the feasibility of building a precision agriculture system. A possible solution for this sub-problem is to use sensor nodes that can be locally configured on a need basis for
monitoring multiple crops cultivated in a single field. Additionally, the controller would have to be programmed to accept different feeds from the crop-specific sensors and correlate the data to produce meaningful reports. These reports could then be reviewed to gather productivity patterns on a per-crop basis so as to identify practices that improve the overall agricultural yields.

The operation of the proposed system, as shown in Figure 4 is as follows:

1. The sensor nodes deployed across the field have different sensors to measure soil moisture, humidity and temperature mounted on them. In addition, they contain transceiver modules, GPS modules and Analog to Digital Converters (ADC).
2. The sensors have to sense these parameters to ensure the farms have the crops growing in ambient conditions.
3. Once the conditions are analyzed, the information is sent to the ADC in the node and the analog signal (analyzed information) is converted to a digital signal.
4. The digital signal obtained is now sent to the base station across the farm to check for anomalies in the conditions.
5. The nodes have to ensure that they form a mesh network in the field to ensure the data collected traverses across the farm to the gateway.
6. The nodes send their data to the Network Coordinator (NC), which is responsible for forming and maintaining a network and all the associated information.
7. The NC will forward the information to the gateway; its role is to relay the data to the Base Station (BS).
8. The transceiver at the BS receives this information and feeds it to the system.
9. The values of the different conditions are compared with the threshold values. The thresholds are set up with respect to the best possible conditions that can be provided to the crops for their best growth.
10. If the obtained values are different than the set threshold, the farmers are alerted by sending a SMS using the GSM Module. The obtained coordinates of the sensor (using the GPS module) in the farm can also be sent in the text message.
11. The system attempts to bring the conditions back within the threshold limit. Thus, the controller can send actuation signals to systems calculated based upon the current value obtained and the threshold value.
12. This actuated signal is sent by the controller from the BS to the gateway, which then forwards this signal to the actuators deployed across the farm. For example, if the soil moisture content is found to be low, in using the actuators, we can start of the sprinklers connected to irrigation pipes to make sure the moisture content is restored to the level required.
13. We can improvise on this basic system by adding intelligence in the sensor nodes. We can put a controller in these nodes and check for the sensed values and compare them with the set threshold. If it is different, they will be forwarded to the BS to take appropriate actions to restore the ambient value for the crop’s best growth.

There are three factors that have to be considered while implementing WSN in agriculture [12].

a. Environmental conditions like speed of wind, temperature and humidity.

b. Plant or crop variables like type of plant and size.

c. Soil variables like soil moisture and chemicals in the soil.

For example, if there have been torrential rains in a particular area, then it must be ensured that the resistance values of the sensor nodes do not change over the tolerance range due to the moisture content in the lead wires. Further, we also have to make sure that the chemicals in the soil do not react adversely with the inductive lead wires in the sensors. Also, the kind of crop is very important because the parameters which are monitored depends on the crop. For example, for a food staple like rice or barley, the water level is monitored and for apples, the temperature is monitored.

Another factor that further results in damage of crops is over-irrigation, where more than the required amount of water is provided in the fields [13]. Thus, it is required that we maintain an efficient irrigation mechanism that would keep track of the water level and then provide the adequate
amount of water in case of any shortage. This practice has two advantages [13]:

a. Water waste is prevented, thereby saving lots of money to the farmers who spend a lot on water supply.

b. When the plants get too little or too much of water, they get damaged. So, providing the right amount of water will prevent damage to the crops.

One more feature that can be implemented into this system is having a GPRS system in the sensor node which would send an alert signal in the form of SMS to the farmer when the values reported by the sensors across some threshold value [14]. This is very useful since the farmer can then make sure the automated irrigation system is working and providing a second line of defense to the crops against the adverse effects of the climate.

This proposed system is an efficient way to improve crop cultivation in developing countries thereby developing their economy. However, many challenges exist in deploying such a system. Some of them are [12]:

a. Since rural areas have an irregular supply of electricity, it is difficult to have a continuous monitoring system.

b. The wireless sensor system should operate in adverse climatic conditions.

Deploying such a system, will also require a cost analysis. The cost incurred in deploying such a system will depend on the area of the farm, the distance from the monitoring station and the technologies used for communication. It also includes the recurring expense of power and communication services. However, this investment is much less than the loss caused due to the damage of the crops. Damaged crops not only leads to monetary loss, but in countries like India, farmers pledge their homes and belongings to invest on the farms. During such incidents of damage to crops, farmers resort to suicide due to the inability to repay the loans taken for cultivation. Therefore, such an efficient system will have a high return on investment in developing countries and also help in improving the economies of such countries.

VI. RESEARCH RESULTS AND DISCUSSIONS

A. Interviews

To begin with, we conducted interviews of the farmers by visiting various rural villages in different parts of western and southern India. The following table contains the questions and responses that we collected from interviews:

<table>
<thead>
<tr>
<th>Interview Questions</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are you satisfied with the current crop yield?</td>
<td>Southern India Villages: Yes, but it can be better. Western India Villages: No</td>
</tr>
<tr>
<td>What difficulties do you face in your agricultural practices?</td>
<td>Southern India Villages: Major difficulties faced are electricity outages, financial debts. Western India Villages: Major issues include water shortage, outdated agricultural practices.</td>
</tr>
<tr>
<td>What are the current farming techniques that you use?</td>
<td>Southern India Villages: Irrigation farming, Plantation farming Western India Villages: Commercial agriculture.</td>
</tr>
<tr>
<td>Are you open to using new technology?</td>
<td>Southern and Western India Villages: Skeptical about adopting new technologies.</td>
</tr>
<tr>
<td>If no, why are you reluctant to adopt new techniques?</td>
<td>Southern and Western India Villages: Suspicious of being duped by the authorities. Some have traditional beliefs and are superstitious about taking up new technologies.</td>
</tr>
<tr>
<td>Given an advanced technology which would help improve the crop yield, would you be ready to incorporate it in your agricultural practices?</td>
<td>Southern and Western India Villages: Willing to give it a try if assured by the authorities of its promised results.</td>
</tr>
<tr>
<td>What methods would you prefer for learning the implementation of a new technology in your farms?</td>
<td>Southern and Western India Villages: Live demos and training sessions or seminars in native languages to learn the operation of the equipment.</td>
</tr>
</tbody>
</table>
B. Current Prototype Components

As discussed in research methodology, a certain set of components were chosen to make the prototype cost and power efficient and at the same time make it easy to use. The following are the list of components that we used to make our prototype:

1. **Controller** - The “brain of our system” – the 8051 microcontroller is used in the prototype since it has sufficient compute power for building the model and is cheaper than other alternatives like ARM, Raspberry Pi and Arduino. The NXP P89V51RD2 is an 8051-based microcontroller operating at 5V and 0-40 MHz. It has four 8-bit I/O ports, serial peripheral interface (SPI) and 1K on-chip RAM [14].

2. **GSM module** - GSM was selected as the communication technology for the prototype since cellular networks are better deployed in rural areas than broadband / Wi-Fi and coverage is comparatively better than other WPAN technologies like ZigBee, Bluetooth, etc. SIM900 is a 5V, Quad-Band GSM module compatible with 8051 microcontroller.

3. **GPS module** - GPS was decided to be used in the prototype to help the farmers obtain and thus know the exact location of the anomaly that occurs in farms. The GPS is used to provide the latitude and longitude of the anomaly. Questar G702 is a GPS Receiver that persistently tracks for satellites and in this manner gives precise location information.

4. **Sensors** - Three sensors have been used in the prototype for sensing the farm conditions for any anomalies, making sure that these anomalies are mitigated and to further ensure the best growth conditions for the crops. Soil moisture sensor is used to sense the soil moisture content, temperature sensor is used to measure the temperature of field atmosphere and smoke detection sensor is used to detect the presence of smoke or fire in the fields.

5. **LCD Display** – A 16x2 LCD display has been used to display the current values measured by the monitoring system. It also displays if text messages are sent out by the GSM module, the emergency message that is sent out in case of an anomaly and also the geographic co-ordinates of the anomaly location.

C. Working of the Prototype

The components described in the previous section were integrated together to form the final circuit of our prototype. The microcontroller was programmed for our circuit functionality using Embedded C language. Embedded C uses most of the syntax of the C programming language and consists most of the tools required to develop the prototype.

The following is the logic/algorithm of our program for the prototype operation:

1. **Controller** –  Embedded C program for the controller includes P89V51RD2.h, ALCD.c, UART.c, ADC123.c, GPS123.c and GSM.c libraries in order to support the features implemented by different modules. The code consists of three functions - the main, the device initialization and GPS function. The main function defines variables and parameters that are used to receive the values from the different sensors which is used for computing optimal conditions. The sensor initialization function is invoked in the main function in order to initialize the sensors with a default value. The GPS function is used to get the latitude and longitude parameters from the GPS module, process the values and hand it to the GSM module which further sends a message to the farmer in case of an anomaly. Every function works in conjunction - the GPS co-ordinates are sent to the GSM module only if the sensor value falls below or rises above a pre-defined set optimum value.

2. **GSM module** - The GSM module (GSM.c) has two main functions – the GSM initialize function which receives the initialization parameters from the main function and the SMS send function which sends messages to the farmer in case of an anomaly. The GSM text messaging has been programmed using the AT commands. The message is sent via a Universal Asynchronous Receiver/Transmitter (UART) module using a prepaid SIM card. The UART module has a function to receive the data from the GSM module and transmit it via the SIM card. A dummy cell phone number has been used in the prototype to check the working.

3. **GPS module** – This module’s (GPS123.c) function is to detect the exact location of the anomaly and report the co-ordinates as accurately as possible to the main function. This is to ensure the co-ordinates are sent to the farmer in the text message, along with the issued warning by the system in case of an ambiguity.

4. **Sensors** – An algorithm was developed to continually monitor the values from the smoke, temperature and soil moisture sensors respectively. The values received by the micro-controller were used to compare it with an optimal value as suggested by the farmers in different geographical regions and for a variety of crops. If the compared value did not meet the optimum requirements, then the location of the sensor which provided the information was retrieved from the GPS module. The optimum values used in the algorithm are 150, 150 and 20 for the smoke, soil and temperature sensors respectively.
5. Analog to Digital Convertor – In addition to the listed components and algorithm, the Analog and Digital Convertor module (ADC123.c) was used to convert the analog signal from the sensors into digital for the micro-controller to understand the input values coming in from the sensors.

The developed code was converted into Hex format using Keil software and then burnt into the micro-controller using the Flash Magic software, which is a tool for programming NXP microcontrollers. Figure 5 below shows the circuit of the designed prototype using the components explained above:

![Prototype Circuit Board](image)

**Fig. 5. Final Prototype Circuit Board**

**VII. FUTURE SCOPE**

The prototype we implemented is just a basic setup of our proposed system. We can undoubtedly strive to improve its performance by using some other alternative technologies, a few of which are discussed below:

A. Wireless Technologies

ZigBee is a WPAN technology (IEEE 802.15.4 standard) that was developed for low-cost, low data-rate and low-power networks [11]. As mentioned in [11], ZigBee helps in provision of a self-organized, multi-hop and reliable mesh networking with a long battery life. It has two devices called the Full-functional device (FFD), which can be implemented in three modes – PAN coordinator, coordinator or an end device, and a reduced functional device (RFD), which can be used for low memory and low data rate applications [11]. ZigBee also consists of the APL layer that helps create interoperable products like home automation and precision agriculture [15]. In [2], M. Keshtgari and A. Deljoo mention the extension of ZigBee technology to real-time field monitoring, a remote field machinery operation and automated irrigation control, after their simulated analysis of a ZigBee-based mesh network. ZigBee receiver modules can be used as wireless sensors to form an effective mesh network where they help in coordinating and managing the network, and their performance would be based upon their deployment design across the farms. It would help collect information from the fields and send it to a centralized controller for analysis and for performing any further actions, if required.

Bluetooth is another WPAN technology (IEEE 802.15.1 standard) developed for connecting multiple multi-vendor technologies for wireless communications. Today, Bluetooth has designed the Bluetooth Low Energy (LE) which has been developed for low-power Internet of Thing (IoT) applications. As explained in [16], development of small sensors with tiny cell batteries that can go on for months, has been possible by the use of LE technology. Attempts are also being made to power these sensors using solar or kinetic energy [16]. This looks like a perfect fit for sensor network deployment in farms for precision agriculture. The use of LE wireless sensors at our farms would make this a power and cost efficient WSN.

Wi-Fi (IEEE 802.11 standard) is another Wireless technology developed for LANs. It helps obtain Internet connectivity along with user mobility in a network. Devices can also create ad-hoc networks if they can operate independently. Wi-Fi access points can be deployed in the farms, forming ad-hoc networks for communication within farms and can send the information to the central monitoring system.

LTE Unlicensed is an upcoming wireless technology in LTE networks that make use of the unlicensed spectrum. LTE Unlicensed co-exists with Wi-Fi and operates in 5 GHz UNII-1 and UNII-3 bands. This technology has helped provide better coverage, faster data rates and lesser lag time. Listen-before-talk approach makes sure that it does not interfere with any co-existing wireless technologies. LTE unlicensed has a good scope of development and deployment in applications like precision agriculture due to its advantages. This will ensure faster detection and thus faster notification to the farmers about any anomalies in the fields. Upgrading the currently deployed cellular networks to support LTE unlicensed would be greatly beneficial in the future, even for precision agriculture.

LoRa is a wireless technology that has been developed to enable low data rate communication over long distances by making use of sensors and actuators [20]. It has a great deal of application in the Internet of Things devices. As our proposed solution includes various sensors and actuators, this technology can be used to get long range communication with less cost. Since the size of agricultural lands are huge to be coverable by existing wireless technologies. LTE unlicensed has a good scope of development and deployment in applications like precision agriculture due to its advantages. This will ensure faster detection and thus faster notification to the farmers about any anomalies in the fields. Upgrading the currently deployed cellular networks to support LTE unlicensed would be greatly beneficial in the future, even for precision agriculture.
B. Controller Boards

The Beagle Board is a low-cost single board computer that has a low-power Texas Instruments processor which provides laptop-like performance. It is based upon OMAP3530 application processor with an ARM-Cortex, running at 720 MHz [18]. The highlight of this board is the USB 2.0 OTG port that can be used to power the board or for any flexible expansion delivery [18]. PC peripherals can be connected using the USB with an adapter for a desktop-like experience [18]. Its processing power makes it one of the best controller boards to be used as a monitoring system for precision agriculture for faster input and output data processing for quicker responses to any issues in the farms.

The Raspberry Pi is a low-cost and small-sized computer that can plug into any device and provide desktop-like experience, along with connecting and browsing the Internet. It has a processor, memory and ports that are similar to ones found on computers, including USB ports. They are available in different models like Raspberry Pi A+, Raspberry Pi B+, Raspberry Pi 2 and 3 and so on [19]. The latest version includes Camera/Display Serial Interfaces 802.11n Wi-Fi, Bluetooth and 1.2 GHz Quad Core processor [19]. There are many new features that make it an ideal candidate to be the controller or the “brain” of the precision agriculture system. Due to its in-built wireless technology features, it can easily integrate and be a part of the Wireless Mesh networks deployed across the farms for quicker data access.

The Arduino board is an open source platform which can be used to read inputs from various devices attached to it [20]. It consists of a hardware board which is the microcontroller and also software which can be programmed on a computer and burn on the physical hardware. The coding language used by Arduino is a simplified version of C++ [20]. Arduino has different boards such as Arduino Uno, Lilypad Arduino, Redboard, Arduino Mega, Arduino Leonardo [20]. There are various sensors which can be attached to the Arduino board such as the temperature sensor, pressure sensor, a light sensor and many more. Due to its ease of use and a lot of online resources and blogs for the same, it is one of the possible choices as a microcontroller.

VIII. BUSINESS PERSPECTIVE – COST ANALYSIS

With the launch of every product, it is essential to perform an interdisciplinary analysis on the costs involved and the return on investment.

Similarly, with our prototype, it is necessary that we analyze the costs involved in the investment and the subsequent selling price of the prototype and the expected profit. This could be valuable in attracting investors, to expand and scale the business.

The cost of the components in the prototype in Indian Rupees (INR) are as follows:

a. 8051 Microcontroller (Philips P89v51RD2): INR 400.
b. GSM Module: INR 900
c. Smoke Sensor: INR 300
d. Soil Moisture Sensor: INR 100
e. Temperature Sensor: INR 150
f. ADC: INR 800
g. GPS Module : INR 900
h. LCD Display: INR 200

The total cost of the components is INR 3750. Fabrication costs could be around INR 50. The total cost of the unit would be 3800 INR. Keeping in mind, a profit of INR 200 per unit, the selling price of each unit could be INR 4000 ($60 USD).

In the beginning, to market the device and increase customer base, the following steps can be employed:

a. Offers such as selling the first 200 units at half the cost could be provided.
b. Distributing videos in regional languages demonstrating the operation and the effectiveness of the product. Demonstrating the efficiency and the effect of using the device on farms which have been damaged due to poor irrigation practices.
c. Establishing partnership with the regional agricultural universities to train and induce an awareness among students regarding the use of this device.

IX. CONCLUSION

Developing countries like India, Pakistan and Bangladesh heavily depend on agriculture for their economy. Therefore, it is extremely essential that agriculture makes use of technology to increase the yield, thereby improving economy and wellbeing of the people.

In these countries, where the literacy rate is not extremely high, especially in rural areas, it is necessary that the technology being employed in agriculture is acceptable to the rural people. Also, it must be cost and energy efficient so that, the rural people who do not have access to economical resources also can afford such products and improve their farms’ produce.

The prototype developed in this capstone aims to resolve these barriers to entry which are energy efficiency, cost efficiency and accuracy. The prototype makes use of a GSM module and an 8051 micro controller which consume very little power. Further, they are cheap when compared with other alternatives like Zig-Bee, LTE – Unlicensed, Wi-Fi or LORA. The prototype demonstrated a considerable level of
accuracy with respect to the temperate, the soil moisture level and the presence of Carbon Di Oxide level in the atmosphere.

This prototype, if developed employing certain other aspects as defined in the future scope section of this paper, can be used to alleviate the agriculture scenario in these developing nations and also proving to be a good business model in the developing countries’ market.

REFERENCES


