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Pest detection and control techniques using wireless sensor network: A review

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Abstract
Pakistan is an agricultural country which depends on agriculture and crops for its economic survival. WSN is an emerging technology all over the world and it is used in agriculture for monitoring different parameters. In this paper we review literature related to general agriculture monitoring, pest disease monitoring, and different pest control mechanisms. We analyze and classify pest control mechanism in technological, non-technological and integrated solutions. Then we compare the pest control mechanisms based on their effectiveness, cost and other performance parameters. Finally, we analyze the feasibility of pest control mechanisms based on the use of WSN for farmers in developing countries.

Keywords: wireless sensor network (WSN), Pest Monitoring, Detection Techniques, Precision Agriculture

Introduction
Pakistan is an agricultural country and agriculture constitutes the largest sector of the economy. Majority of the population, directly or indirectly depends on this sector. It contributes about 24 percent of gross domestic product (GDP) and accounts for half of employed labor force and our agro based products is responsible for 80% of the country's foreign exchange earnings as well as supplying the raw materials needs of the other industries of the country [3].

Pakistan loses over 2.3 million cotton bales every year due to the cotton leaf curl virus (CLCV), which is considered to be the one of the top reasons for Pakistan's low cotton yield, particularly in the Punjab region. CLCV is a deadly virus that is transmitted by a small insect called white fly: a sucking pest of cotton and vegetables [1]. Similarly, recently, a new problem, generally known as '*reddening*' or '*red-leaf-disease'* is now becoming a serious problem in various cotton crops belts of Pakistan especially in the Sind region [2].

Cotton serves as a perfect host for variety of insects. The cotton pests in our region have greatest diversity. More than 90 insects and mites are found to be damaging for the cotton crop in Pakistan. Major threats for cotton crops in Pakistan are American (*Helicoverpa armigera*) and Pink (*Pectinophora gossypiella*) boll worm, Cotton leaf folder (*sylepta derogata*), spotted boll worm (*Earias insulana*), Army worm (*spodoptera litura*), Thrips (*Thrips tabaci*), White fly (*Bemisia tabaci*) [3] which spreads rapidly and are difficult to control without loss. Existing systems for forecasting the disease and its spread mostly depends on farmers' personal monitoring of crop and their previous experiences. After certain age of plant the farmer has to inspect personally each plant and if symptoms are found, pesticides and fungicides are immediately applied in huge quantity to prevent disease. This can defined as the extent of the real time monitoring or data. The drawback of this activity is that not only is it a time consuming and resource wasting activity, but also that one has to wait to detect symptoms, and hence one is unable to detect the disease at an early stage.

Cotton is one of the major agriculture products of Pakistan. Pakistan is the fifth largest producer of cotton in the world, the third largest exporter of raw cotton, the fourth largest consumer of cotton [41]. Farmers need to be very careful from the initial stage to get maximum quantity and good quality of product. To reduce the cost of production and enhance the quantity and quality of cotton, latest technologies can help. Technology can help farmers to monitor crops efficiently and potentially remotely detect destructive insects / pests and to prevent their relevant disease in early stage [4].

We believe that technology could help the farmers to monitor different types of parameter timely and cost effectively. There have been several studies of WSN in agriculture for general

parameter monitoring [5, 6, 9, 10, 11, 12] but our focus is mainly pest control especially with WSN. It boosts their output as is shown by the fact that other countries are using it and benefiting from it.

The paper is arranged as follows; in section II we described wireless sensor network (WSN) and its application in agriculture. In section III we present a brief review of existing pest monitoring systems from literature. In section IV we present review of pest control methods and its classification. In Section V, we present their comparison with our analysis. Finally, we summarize the paper and highlight future work in section VI.

2. Wireless Sensor Network

Wireless sensor network (WSN) has proved to be very useful in specific applications requiring monitoring of real time data. Precision agriculture is among one of them. Recently the agriculture domain has incorporated WSN to support its major monitoring operations. Precision agriculture is the science of precise understanding, estimating and evaluating crops condition with the aim of determining the proper use of fertilizer and the real needs of irrigation, both sowing and harvesting seasons [5, 6, 7]. But now we associate it with more complex and precise tasks like monitoring different parameters, pest indications, related disease and crop concurrent status.

Precision agriculture (PA) is an integrated information and production-based farming system that is designed to increase long-term, site specific and complete crop efficiencies, productivity with profitability as well as minimizing unintended impacts on wild life, the environment and equipment failure [5, 6] Figure.1 shows wireless sensor network deployment for agriculture.

A WSN is an ad-hoc network; generally WSN does not require infrastructure like other technologies to operate. It may consist of multiple unassisted embedded devices (nodes) which process and transmit data collected from different on-board physical sensors (temp, wetness, humidity, pressure, soil moisture etc.). It also includes base station which acts as gateway between nodes or nodes and end user. It could be a single or multi hop network.

Many WSN applications have been proposed so far in precision agriculture, which include monitoring vineyards in Italy and Spain to various fruits vegetable as well as plant cultivation in rural areas and green houses in Portugal, Ireland, Netherlands; and some research is still going in India as well [6].

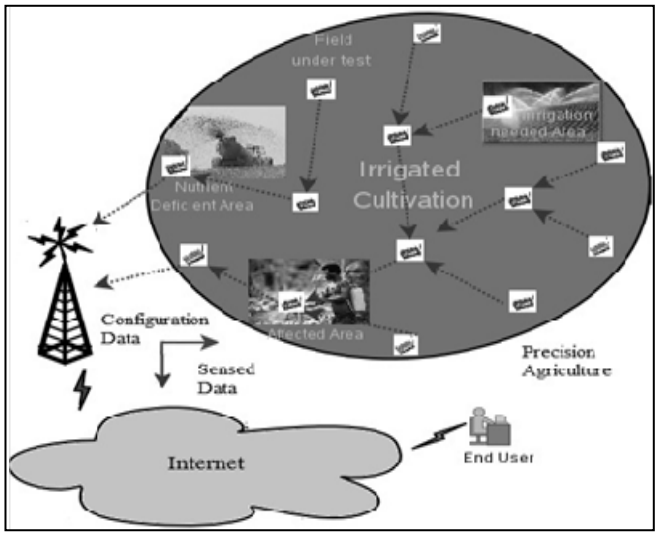


Fig 1: A Typical WSN deployment for agriculture applications [6]

WSN technology has several benefits as well as limitations. Controlled irrigation and proper use of fertilizer can reduce wastage and preserve resources. Proper use of pesticides could reduce our loss and maintain and improve quality of product and boost profitability. WSN has various issues which include limited power, physical security of hardware and software and security issues in routing operations; they are all still need to be addressed.

PA is turning into a modern science with the help of wireless sensor networks and other technologies. In future PA will deals and take care of following branches of agriculture science with technology orientation.

Environment Shield: PA helps to reduce Nitrogen, Methane and Carbon and other dangerous gases and liquid emission.

Crops Surveillance: Primarily focus is to monitor and understand needs of crops according to weather and managing available resources.

Proficient Resource Distribution: WSN can help to reduce wastage, preserve precious resources and effective utilization them. In results efficiency has been improved, efforts decrease and boost economy [10].

Future Tool: Farmers will use this WSN technology for their benefits in future. Many agricultural areas could benefit if used properly. Some agriculture areas are still in research and among researchers like pest monitoring and control, immediate need of pesticides, monitor need of water and fertilizer [11, 12, 13]

Wireless sensor network is now being increasingly used in the agricultural domain. WSN has been frequently used for general monitoring of the agriculture field for example [5, 6, 10, 11, 12, 13]. However, few researchers have focused on pest detection and control using WSN. And therefore in this paper we have reviewed pest monitoring and control papers currently in use.

3. Pest Monitoring Systems

In this section, we review the current trends in the use of WSN's across the subject of pest monitoring and control.

Pest detection and control is at least as old as agriculture because there has always been a need to keep crops free from pests. A number of techniques so far proposed for pest control in agriculture using wireless sensor network. In this part of the paper we will review and present different types of proposed mechanisms and techniques and analyze the research work of different authors and compare the relative pros and cons. Table I illustrate crops and their related pest which are reviewed in literature.

Table I: Crop vs. Pest

CROP	PEST/ Disease
Cocos Nucifera L	RPW Larvae [16]
Grapes	*Downy Mildew* [4]
Sugar Cane	Shoot borer, Rood borer [5]
Groundnut	Vectors (e.g. *Thrips*) [8]
Green houses	RPW [14]
Date Palm Tree	Red Date Palm Weevil (RDPW) [18]
Vineyard	North American leafhopper [19]
Ivy Geranium, Impatiens	Two spotted spider mites (TSM: *Tetranychus urticae*) [27]

In [8] the authors' review the crop-weather-pest relations and data mining with WSN for peanut crops pest and disease interaction in India, The research work is a part of the Indo-

Japan multi-disciplinary ICT initiative called geo-ICT and sensor network based decision support system for agriculture. They conduct an experiment to understand the crop-weather and pest relation using wireless sensor network and independent pest and disease dynamics of peanut crops. It uses many data mining techniques to turn the data into useful information and correlation of crop / pest / disease and climate field. An attempt has been made to understand the hidden relationship between interrelated disease and pest and weather parameters. In the end, they develop a collective prediction model, which could aid future respective improved measures.

In [4] authors proposed a solution to detect specific disease (downy mildew) in Grapes in India at a very early stage. The real time system that detects downy mildew pest / disease is based on just weather data. The proposed system is to provide a remote node with ultra low cost and the user has to maintain only a remote node instead of main node at a farm. A central server can be accessed through web applications to get all details of current weather conditions and disease forecast which depends strongly on climate of the farm plot by plot as shown in Fig.2.

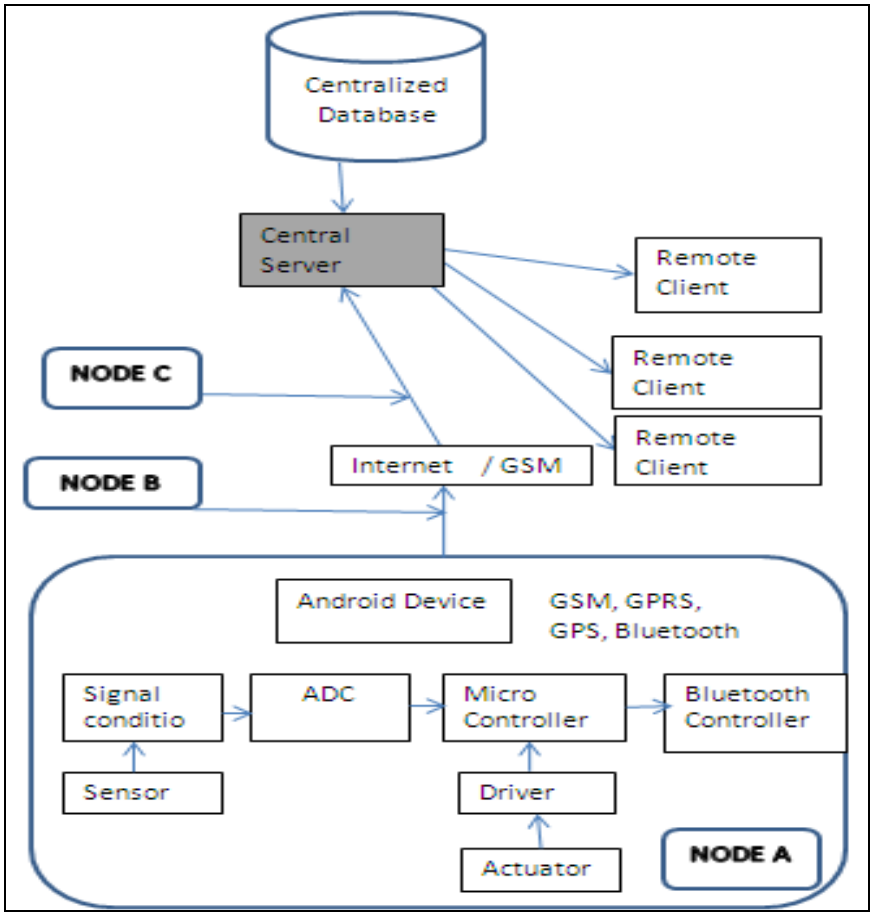


Fig 2: Layout of proposed System [4].

In [14] authors proposed a solution for monitoring traps which they used to capture pest by means of image sensors. The authors proposed a low-cost system based on battery powered wireless image sensors, which are able to capture and send images of the trap contents to a remote control station with specific frequency demanded by trapping application. These image sensors accurately monitor pest population with a higher temporal resolution. During this monitoring process no human intervention is demanded. According to authors there is a significant reduction in monitoring cost as well. However there seems to be no intelligent image processing activity.

Whilst the focus of this work is mainly on red palm weevil (RPW, Rhynchophorus Ferrugineus (Oliver)) but it is not limited to that pest. It could be used for monitoring many other kinds of pests. Pest monitoring proposal is based on RPW traps equipped with wireless image sensors that are spread over the monitoring area forming a wireless Image sensor network (WISN). Trap monitoring process which works on unattended mode has some extra benefits like it reduces the monitoring cost: it is programmable and higher temporal resolution of trap monitoring data. In addition, monitoring data can be available in real time through an internet connection.

There have been a number of valuable studies to monitor pest insect using latest technologies. However, none of these studies provide a self-sufficient monitoring system based on low cost image sensors covering areas with very low energy utilization. High scalability with low power consumption made it possible to deploy both green houses and larger plantations. It is also used for several kinds of insects instead of some specific insects. Using image recognition algorithm is able to identify RPW individuals with a success rate higher than 95%. All corresponding meta data with timestamp, GPS location, processing, results etc are conveniently store in the control station, they can be accessible in real time by means of internet service provider available at the location of control station.

In [16] authors proposed a monitoring system to detect red palm weevil (RPW) larvae with the help of acoustic sensor devices. Authors mentioned that acoustic detection of this pest is the best and most cost-effective solution among all. According to authors it is also able to distinguish between various pests which give this technology an edge over others. The proposed system is for efficient sugarcane crop production. The system would employ an acoustic device sensor for monitoring the pest's noise level and whenever the noise level crosses the

threshold it will notify to the farmer of the specific area where the infestation is occurring. Using this technology the need of the farmer to go to each and every part of the crop and perform survey is reduced significantly. The acoustic sensors node will be connected to the base station to which each sensor will transmit the noise levels whenever the noise level crosses a predefined threshold level.

The base will then transmit the information to the control room computer which will indicate to the farmer where the infestation is occurring so that the necessary action can be undertaken. After successful identification a farmer can then take the necessary measures to spray insecticides over the crops and will aid detection of infestation at a very early stage and will greatly reduce the percentage of sugarcane crop being destroyed annually. The proposed system will be able to cover large amount of area with very low energy consumption.

In [17] the authors proposed an efficient protection mechanism of palms from RPW larvae. The feeding habit of the RPW is concealed, very much like termite in wood. They can be detected acoustically by the noise emitting from them. The infestation whereby detected only during the last stage and farmer come to know of the problem only when the tree is about to die. During the detection phase, the sensors along with communication modules containing a transceiver are attached to a tree and latched to the network of the access points nearby. In this proposal each access point receives the information from eight palms in the vicinity of its radio range.

Table II: Pest control Mechanisms in literature using wsn.

Papers / Authors	Analysis of Symptoms	Identification of Pests	Management Pest
Sarika Datir 2014 [4]	Real time system that detect Downy Mildew pest based on weather data.	No identification mechanism.	Spraying of pesticides automatically if disease probability is Severed.
K Tripathy 2013 [8]	Weekly data collected manually	No identification mechanism. Specific crop, pest and disease.	Real time decision support system for prediction of disease
O. Lopez 2012 [14]	Schedule image captured.	No identification mechanism	Removal of pest by Traps.
N Shirivastav 2013 [16]	Continuously observe the noise level being collected by the various sensors and comparator that is set to a particular threshold level	No identification mechanism for specifying pest.	An alarm signal to turn inform the operator and farmer can then take the necessary measures to spray insecticides
Srinivas 2013 [17]	Acoustic activities of larvae i.e. chewing, crawling, emission and quick oscillating sounds.	Comparison of detected noise / sound with prerecorded sound of RPW.	No control measures are mentioned.
Mohammad A. Al-Manie 2007 [18]	Acoustic emissions produced by the RDPW inside the date palm tree were successfully recorded And identified using special sensor.	Comparison of detected noise / sound with prerecorded sound of RPW.	Isolating or treating the infected trees with appropriate chemicals.
Mauro Prevostini 2011 [19]	Real time prototype data collection and based on weather data assume that disease vector is spreading. Which will use the temperature readings to simulate the spread of the disease vector	No identification of pest mechanisms exists.	Pesticide, when it is absolutely necessary,.

The received information is routed to the server via the secondary access point that is wire connected to the server. The main server processes the received information to analyze the current scenario on the Palm tree. Each tree is attached with the sensor apparatus. The recorded sound signals are continuously transmitted to the nearest access point (repeater) from which it is sent to the server. The sounds were recorded and a MATLAB program was used to calculate the fundamental frequency of the sound. No action or management of pest is mentioned and they used NS2 for simulation.

In [18] the authors proposed a technique to detect hidden insect infestation of date palm tree (phoenix dactylifera L) with the help of acoustic instruments. They use acoustic sensor for early discovery of the presence of a destructive insect pest commonly known as the red date palm weevil (RDPW) its scientific name is Rhynchophorus ferruginous (Oliver). They record acoustic emission produced by the RDPW that infect date palm trees and then analyzed using signal processing methods. Acoustic sensors such as special probes are inserted in the palm tree trunk in order to record sounds produced by the insect especially in the early stages of its life known as larval stage where the feeding and other activities of insects are at their maximum. Once the sound produced by the pest is available through the usage of acoustic sensors.

In [19] the author proposed a WSN prototype with related algorithm for detection of North American leafhopper which is the vector for bacteria that causes a disease named flavescence doree that ruin wine crops each year. They worked on an initial prototype of a small wireless sensor network as well as on an algorithm that could be used to calculate the spread of the disease. For detection purposes the sensor will be placed directly on grapevine stems and shoots to take air temperature readings. Then the data will transmitted to control room computer over wireless sensor network; which will use the temperature readings to simulate the spread of the disease vector. The warmer the temperature becomes the faster the leafhopper will proliferate. Once a critical threshold has been reached, the system will issue an alert signal enabling winegrowers to act at the right time. Alongside this approach, pesticides will only be used when it is absolutely necessary. At the end this protects both the environment and worker with their crop. Winegrowers should be able to reduce their pest control costs by about 25% each season with this new system. A disadvantage of this method is the cost and time involved in placing these WSN across the crop region.

Table II provides a summary of some of the pest control mechanism using WSN surveyed in this section, where sufficient information is available in the original papers. The advantages and best potential use of the presented sensor technologies are shown in agriculture. We observe that there is

still a huge gap in pest management using WSN.

This review is expected to evaluate the effectiveness of different pest management options in local context. A lot of research has been done on monitoring of agriculture through WSN for example. [4, 8, 14, 16, 17, 18, 19] However, few of them were concerned about the use of WSN in pest detection and control. Therefore, there is a need for development of a system for detection and control of pests in crops.

4. Pest Control Methods

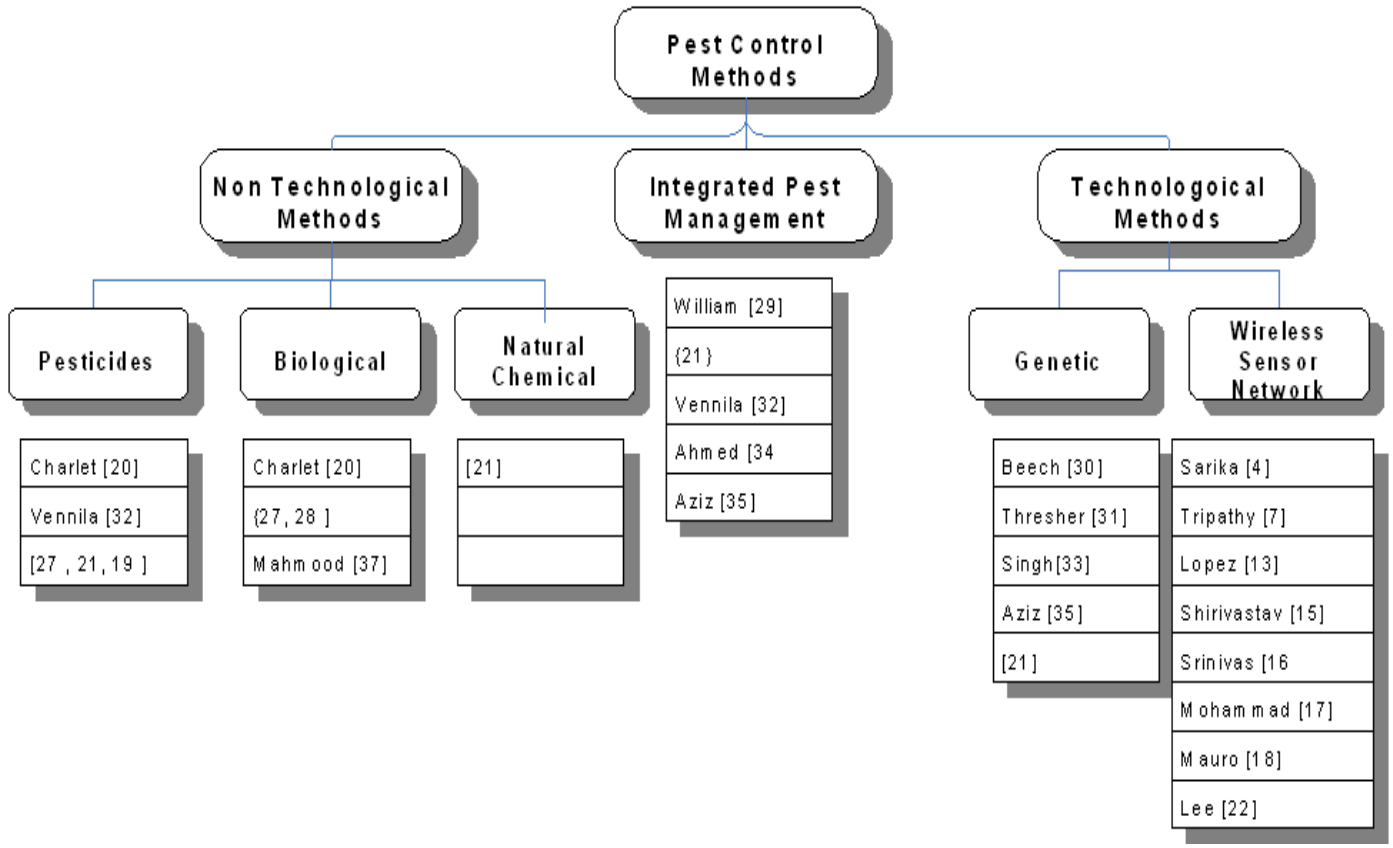
Chemical pesticides date back 4500 years, when the Sumerians used sulfur compound as insecticide. The rig Veda, which is about 4000 year old, also mentions the use of poisonous plants for pest control. As early as 1911, cultural control in the form of removal of cotton sticks by first of August every year was made compulsory by law to prevent some pests like bollworm on cotton in India. In the 20th century, the discovery of several synthetic insecticides, such as DDT, and herbicides boosted this development. [33] We review only major methods with the aim of appropriate solution.

In traditional cotton pest control methods, the strategy heavily depends upon the severity and infestation of pests. Choice is available for farmers for sucking pests during early phase of crop and bollworms during the mid and late seasons. Prevention of key pests and their control is essential for good and healthy production. Now we may divide pest control methods into three categories. First is based on non technological pest control methods while second is those using technological solution and integrated pest management is third category. Figure 3 shows our classification of pest control methods.

a. Non technological Control methods

Chemical pest control is still the predominant type of pest control today [20]. Some pesticides target specific insects, rodents, weeds or fungi, while others are broad and manage a wide range of unwanted organisms. There is a smart move to reduce the use of pesticides in favor of more environment friendly methods of pest control. Although pesticides, that is chemicals that kill or manage the population of pests, have been used for many years, several alternative pest control methods have been developed.

One common alternate method used for controlling pests is biological control, which is when natural predators of the pest are introduced to prey on or parasitize the pest. Biological control as a management tool dates back over 1,000 years when ancient Chinese citrus growers used ants to control caterpillar larvae infesting their trees. It is one of the safest methods of control since it is not toxic, pathogenic or injurious to humans [21]. When using this method, farmers get natural predators of the pest and release them into their fields so that the predators can manage the pest population.



Although biological control can be very beneficial but are prone to cause problems as well for the environment. Sometimes, biological control organisms begin to take over an environment and can cause harm to non-pest organisms. Unfortunately, once biological control organisms are introduced into the environment, they are almost impossible to remove. One more disadvantage of biological control is, if they act differently than expected, it could be possible that they can do more damage than the existing pesticides they are supposed to eliminate.

Natural chemical control is another alternate method of pest management that utilized chemical compounds found in the environment to manage pests. The most common used natural chemicals are pheromones and hormones, which are specific to the pest species being targeted and have limited influence on other species [22].

b. Technological Control Methods

As agricultural technology has advanced under the pressure of increasing population and rising quality of life expectation,

scientists have developed alternative methods of pest management that focus on the genetics of the organisms. Genetic control is the method of pest management where the crops are genetically altered so that they are resistant to pest and diseases caused by pests. Crops can be genetically altered in ways that produce chemical or physical barriers to prevent harm from pest [22, 34].

Genetic control has made it possible to reduce the harm done by pests. Genetic modification has so many benefits including longer shelf life, enhanced agronomic traits, insect resistance and tolerance to various environmental agitations. There are some worries over altering the genetics of organisms. Many people are concerned that by genetically altering crops it might lower the nutritional value of the crop, cause harm to beneficial organisms' lower overall genetic diversity and create new food allergies.

All alternate pest management methods have been very useful in their specific conditions with specific crops: they also have some related issues with related to them. Due to associated issues pest control science still wide open for research and still scientist searching for new options and technology to reduce the existing risk.

With the advances in electronics and information technologies, advances are also expected in the use of lights with various sensing systems have been introduced for specialty crop monitoring and production. Latest development in this field is the introduction of wireless sensor network for monitoring pest and precision agriculture. Timely and accurate information concerning the spatial inconsistency within crops is very important. Sensing technology for pest and disease detection is most advanced and can provide the data required for site specific management. Sensing technologies for disease detection is based on more complex communication between plant and sensor and making them more difficult to implement. Some European countries and India are using WSN for precision crops and monitoring pest with some pest control methods [13, 23].

c. Integrated Pest Management

In addition to these specific alternative pest control methods, a complex managements system, known as integrated pest management system (IPM) has also been developed. Integrated Pest Management (IPM) is an efficient and environmentally sensitive approach to insect control that relies on a mixture of common pest control practices. IPM programs use current, comprehensive information on the life cycles of pests and their growth and interaction with environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical way, and with the slightest feasible risk to people, property, and the environment. IPM is not a single pest control method but, rather, a series of pest management evaluations, decisions and controls. IPM first sets an action threshold, a point at which pest populations conditions specify that pest control action must be taken. The level at which pests will either become an economic threat is critical to guide future pest control decisions. Not all insects, weeds, and other living organisms require control. Many organisms are harmless, and some are even beneficial for crops. IPM programs work to monitor for pests and identify them accurately, so that suitable control decisions can be made in combination with action. As a first line of pest control, IPM programs work to manage the crop to prevent pests from becoming a danger. Once monitoring, identification, and action indicate that pest control is required, and protective methods are no longer effective, IPM programs then evaluate the proper control method both for effectiveness and risk. Effective, less risky pest controls are chosen first, including highly targeted chemicals, such as pheromones to interrupt pest growth and mating, or mechanical and biological control, such as trapping or weeding. If further monitoring, identifications and action thresholds indicate that less risky controls are not be able to control, then additional pest control methods would be employed, such as targeted spraying of pesticides. IPM is become an essential component for a sustainable cotton production in developed countries. Brute force spraying of non-specific pesticides is a last option. [22, 30, 33, 35 36]

Development in wireless sensors technology techniques enable us to take better decision based on information received from data monitoring. The literature reviewed indicated that there is a gap in the use of WSN in detection and management of pest control.

5. Comparison of Pest Control Methods

Pest control techniques are widely studied these days but still a huge vacuum exists to determine appropriate competitor to pests which is economically compatible, ecologically viable and environmental friendly. To reduce current challenges in pest control more efforts are required to develop more intensive integrated pest management system and adopted into practice. Similarly, environmental impact of agriculture these days is at least in quantitative terms, practically well conventional and this sector is regularly known as guilty of pollution [24, 25, 26, 27, 31].

Pesticides or chemical control is a legacy pest control method. It has been in use for hundreds of years and its effectiveness is very high compared to all other methods. But the condition of pesticide approvals is frequently changing as many of the older generation pesticides development (one of the example is DDT) in the 1950s-1980s are under review these days [39, 40]. Due to several draw backs regarding environment and human health, world health organization and pesticides action network banned it in several European countries. Moreover Insurance companies do not cover crop insurance because of their draw backs. Even if these chemicals applied according to label instructions, it is harmful [39, 40]. In Pakistan, our farmers use it badly in their crop for pest control. According to local farmers expenditure of treatment plays a vital role for us. We always prefer local manufacture chemicals. This is neither environment friendly nor is it good for human health and product. It is observed that biological control is neither cost effective nor exclusive as chemical control is. Other parameters like human health, environment has much better values as compare to chemical. Sometime biological control proved dangerous to the crops because those pests which were sent to control pests destroyed the crop themselves.

Application of genetic control is increasing and it has been the most rapidly adopted technology in the recent period of agriculture and food biotechnology [34]. However its implementation in crops has led to significant panic about their safety and strength. We also know that every innovation bring own risks to the environment, product and industry. The reduction in use of chemicals for pest control is most obvious environment benefits along with many others.

We always adopt technology which has comparatively low risk; genetically modified crops available in both developing and developed countries with their potential benefits with some of their risks. The possible risks associated with cultivation and use of destructive plants. Introduction of allergenic protein into foods, damaging effect on other genus and raise biodiversity fear, probable risk associated elements.

Table III: Pest control methods [28, 30, 31, 32, 34, 36]

Pest Control Methods	Cost	Environment Friendly	Human Health	Product Quality	Labor Saving	Effectiveness
Pesticides / Chemical	Low	Low	Low	Low	Low	High
Biological	Medium	High	High	Medium	Medium	Medium
Genetic	Medium	High	High	Medium	Medium	Medium
Integrated Pest Management System	High	Medium	Medium	High	High	High
Wireless Sensor Networks	Medium	High	High	High	Medium	High

Environmental effects, farmers and wildlife health are major hindrance of pesticides. Uncertain behavior of biological control along with uncontrollable by nature attitude. Controversial position of genetic modification is still creating a huge gap for pest control. Integrated pest management approach is gaining momentum in developed countries since eighties although high cost along with some limitations. IPM is an essential part of crop yield which has two important elements. First it comprises a series of measures and second comprises control methods. IPM intention should avoid any predefine set of pest management technique. Current practiced IPM is specific to pest, disease and weeds but it should involve integration of different control processes against any single pest with no exceptions. Effects of IPM vary because of heterogeneity across regions, time, pests and types of crop growth. According to experts it can be a success in any crop or region if it applied over wide areas and strike heavily with the help of background research as well [33].

Besides all pest control methods mentioned above we have wireless sensor network as pest control technique. WSN is new in this industry with this type of application.

Traditional methods of pest control have its own limitation as discussed earlier in this section. Therefore, our focus is on smart, systematic technological solution with low labor cost. These systems could offer high effectiveness with high level of pest / disease predictions. It will enable us to take right decision at right time. WSN with prediction algorithm and application promising us to (i) reduce cost and efforts to control pests, (ii) real time monitoring and analysis of their behavior and activities,(iii) provide a platform for studying and applicable solution to similar problem with some desired extensions [37].

When we glance over local circumstance in Pakistan we come to know that our farmers use so many techniques to control pests. The first and foremost is chemical pesticides then biological and somewhere IPM is used. There is a need to develop techniques which encourage natural control as well as other high tech solution [38]. It is also recommended to use technological pest control techniques using WSN. We believe this can provide the farmers an alternate solution to chemical insecticides in developing countries like Pakistan. Table III presents the comparison of pest control methods based on define parameters. Through which farmers can make decision about their crops and yields. These parameters include cost, environment, farmer's health, labor and effectiveness of various treatments, impact on productivity. We further categorized them to find out which one would prove more effective comparatively. As we know, some issues of developed countries are in contrast to developing countries. Priorities and needs in develop countries are not similar to developed countries: where human health and environment are more important than wealth; But in some developing countries there is a greater concern for quality of products and its economics [36].

6. Conclusion and Future Work

Today, technology is a stakeholder in every industry. We are in need of technology in every field of life for process automation and effectiveness. Role of technology in agricultural field is increasing due to many reasons. Several challenges exist due to diversity in pest detection and control methods. In this paper we reviewed pest control literature and classify control mechanism as non technological, technological and integrated pest management. We also compared all existing mechanisms with the help of certain parameters.

Comparison and analysis of pest control methods in this paper has encouraged us to use WSN for effective pest control in developing countries with affordable cost. Our focus in future is on designing and implementing WSN test beds for pest monitoring and control system. Designed system will check the infestation at early stage and notify the farmer of the crop where the infestation is taking place. It will reduce the burden of farmers by preventing them to manual monitoring of the field.

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