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Research paper

Wireless Sensor Network (WSN) in Insect Monitoring: Acoustic Technique in Insect Monitoring (A Review/Survey)

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Abstract

Eco-friendly and effective method of white grub control is needed to reduce the impact of pesticide on the environment and the cost of control. The use of nematode as a biological agent to control larvae under soil was positive. The challenge is about the accuracy in time, location and amount of biological control agent required for control at initial infestation of the harmful insects, to reduce the damage the use of wireless sensor network (WSN) is required. Work carried out, sent at a threshold value of CO_2 under the soil determine from lab to greenhouse to open field experiments. Initial stage detection of these insects life cycle is required for accurate time and location for control of these insect pests for resource effectiveness. This location can be communicated to a mobile phone via Global System for Mobile Communication (GSM) with Global Packet Radio Service modules (GPRS). Next challenge is to quantify the CO_2 level from the white grubs as part of soil respiration, and to estimate their population. The farmers could be trained as listeners to survey for acoustic evidence of insects and to identify them by distinctive spectral and temporal pattern. Acoustic detection can be used to estimate the population of white grubs. A hypothesis of 90% success of the combination of CO_2 burst sensing from white grubs (GMM221 sensor) as a generic signal with volatile compound as a specific signal from plant roots under insect attack and using Laboratory Virtual Instrument Engineering Workbench (*LabVIEW*) is considered. In the future, a universal sensor is to be developed for high accuracy with *LabVIEW* monitoring interface.

Keywords: *acoustics; CO_2; communication; control; insects; LabVIEW monitoring; location; pesticides; WSN.*

1. Introduction

The excessive use of pesticides for control of pest results in health hazards (pollution), in view with several disadvantages of unscientific use of it, there is need to reduce or stop its use with public concern over low yield and high cost of production by other alternatives. The main aim of this research is to detect the white grub infestation problem using wireless sensor network (WSN) technology in modern day practice in agriculture with electronics systems. The end result of this research will assist farmer in detection of white grub at early stage to reduce damage. A challenge for the effective way of control of these harmful insects in the field, the challenge is about the accuracy in time, location and amount of biological control agent required for control at initial infestation of the harmful insects, to reduce the damage.The issue of water, soil and pest can be solved by WSN (automatic monitoring) to increase profit, productivity and efficiency in agriculture. A renowned Entomologist known as the father of acoustics used the acoustics technique to ascertain or account for the presence and population of insect pest infestation over a long period of time using audio kit. This research survey will show the aspect and extend to which acoustic technique is utilized for insect pest above or under the soil and the proposed concept of WSN with *labview* monitoring interface. Under the soil **CO_2** is a cue for sensing the presence of insect pest as a larva under the soil [1], the sensing of sound of movement of larva activity and volatile compound release by roots on attack by insects pest [2]. Above the soil, sound of insect is detected. Spectral patterns are examined as a template [3].

2. Acoustic technique review

Asian citrus psyllid (ACP) insect pest is an insect that transfers bacteria from a plant to another and this bacterium does the damages to the crop. The male insect makes a duet-ting sound call to attract the female for mating. Therefore, it was studied that the call by the male can be replied by a mimic using electronic sound e.g. buzzer to disrupt the mating process and as a result reduce the population of the insect and its activity. Most of the harmonics in this experiment where observed to be in multiples of 200 Hz. The reports on the results was on the presence and absence of mimic reply call for the male by the female and the use a software in noisy background to detect male call. The material and method used include a 30cm high citrus tree from a greenhouse and a male and female virgin reared from a research center. A video was recorded to observe the behavior of the insects, an amplifier connected to a microphone to detect the sound made by the male. As in Mankin et al. (2013), synthetic mimic signals were generated using a low-cost micro controller platform (Arduino Uno, Arduino Inc., Ivrea, Italy) connected to a circuit board, a microphone and a piezoelectric buzzer were utilized in the study. The experiment was conducted in an Ana-echoic (vibration free chamber). In the field, wind, birds and movement causes frequencies similar to duet-ting calls. Therefore, to identify male call in noisy background, the programmed micro controller uses Fast Hartley Transform Algorithm for 128 points every 0.1 seconds from 256 points at 800Hz sampling. With background noise it was observed that 6% or 280 samples are ACP calls and 94% from background signals. A template was obtained by iteration using matlab to get 77% male calls and 26% background noises. The male and female were placed on leaves by a walker device and timings were taken for the searching period of the female by the male, the duration of calls made and the contact, all was conducted in 60 minutes. The result of mating disruption and control bio-assays showed that in mating disruption, the pest moves in reverse direction more towards the buzzer than towards the female insect and a longer duration before mating than in control bio assays. It was also observed that different males have different frequency, this variation in male wing beat frequency results in recognition or detection of a male call. It showed that peaks of different amplitude for different multiples of wing beat frequency are different for each male. This observation can be utilized in the algorithm that can be used for future use in call identification. It means that different calls by male were analyzed based on their frequency of call and was observed to vary for different male, as such the algorithm in future may consider such variations in the male frequency and the peak amplitude observed. It was concluded in this experiment that the use of low cost devices to detect male call and mimic a response of the female or make vibration signals is used to trap and disrupt the mating of ACP insect and this can be applied for other pest that are vector or carries of bacteria diseases from one plant to another [4]

Experienced listeners readily distinguished three types of sound with distinct differences in frequency and temporal patterns, intensities, and duration. It was studied that 7% of the sound was identified as clipping activity, 60% as surface sliding, 2% as surface scrapping and 31% as spectral pattern that is difficult to recognize. The detectable sound by Grubs depends on temperature, such that the lower the temperature the lower the sound rates by the Grubs and because of this it makes it less effective in cold weather. With the results obtained, it suggests that acoustic method can be applied as a nondestructive means of monitoring insect's treatment and for biological or ecological studies. Previous acoustic methods were applied to detect presence or absence rather than to identify White Grub specific behavior or activity patterns. This study suggested two (2) different approaches to examine the behavior and activity pattern of white grub. The first method is to use acoustic technology to study the signals for the duration of a behavior or a specific feature that caused such a sound. The second approach is to study the conditions or treatment that caused an overall activity change of the white grubs using the acoustic technology. These changes can be environmentally, like temperature or from experiment. Some predictions were taken which includes; sound rate by white grubs would be proportional to temperature, sounds rate are proportional to weight for a given temperature and the relationship between temperature, weight and sound rate would be different for different species of white grub. Acoustic sensor was made from electrets microphones inside stethoscope heads and the amplified signals were monitored using stereo headphones and a digital audio tape recorder. Third and second instars were breed and put in a cage. To monitor a grub, an acoustic sensor was centered just below the surface of the soil at the top of the cage. Their initial and final weights were taken. The grub was placed at the center of the cage to adjust to the environment and temperature and sound were monitored. At temperature above 13^0C sound was recorded for 3minutes and below 13^0C was recorded for 15 minutes. Different species and amount of white grub (C. lurida P. congrua P. crassissima P. crassissima) for second and third instars were monitored for sounds in different number of days under outdoor and laboratory temperatures. The recorded sound was played back in microphone and an oscilloscope to determine duration and amplitude of the signals. Signals of interest were digitized by digital signal processing and assessed by computer to obtain white grub sound and compared with previous experiment. White grub sound was distinguish from background noise after several studies of the amplitude and duration of the signals in the oscilloscope and analyzed in computer and it was conducted in acoustically shielded box, which background noises was rare. Chi- square analysis was used to compare different sounds from second and third instar at different temperatures and Regression analysis (SAS Institute 1988) was used to examine the effects of soil temperature, initial weight of grub and time on sound rate. But Regression analysis (SAS Institute 1988) cannot be used to analyze weight and instar on a single regression, so Proc GLM analysis was conducted with a model containing soil temperature and instar. Regression analysis (SAS Institute 1988) was used to examine the effects of soil temperature and weight on the combined sound production of the different species. The larvae of four species of white grub produced different sounds. Three of this sounds by the instars were analyzed, the sounds are snaps, rustles, repeated pulses and background noise. No difference was observed in these three different sound types in the second and third instars, but temperature effect on these sound types showed absence of repeated pulses at temperature above 28^0C. Chi- square analysis showed difference in the three type of sound in three different ranges of temperature. This sound classification can be used as a means of identification of insects. Also temperature and grub size strongly affect the sound rate than the specie and time of the day affects the sound rate. A graph to indicate effect of temperature on sound rate relative to time of the day for P. crinita was plotted. The effect of combined sound from all the white grub species on the sound rate production was analyzed and was significant, but the effect of a given weight of specie (**Cyclocephala lurida, Phyllophaga congrua, Phyllophaga crassissima, and Phyllophaga crinita**) at a given temperature to give difference in sound rate was not explored. Larger numbers of white grubs of these different species may reveal differences of behavioral or ecological interest. The effect of instar on the detection of sound was examined and found that second instar produced fewer sounds per minute than the third instar at a given temperature. An alternate method of testing of different sound rate at different temperature can be adopted and it was concluded that for the four species of white grub, it is difficult to use acoustic technique to examine them in the field for temperatures below 9^0C. Acoustic techniques are expensive and time consuming, but are alternatives for nondestructive method of pest monitoring. Microphone together with digital signal processing can enhance detection and acoustic technique has shown the effect of environment on these insects and the laboratory effect as well [5]

Acoustic technologies are either to repel, detect or attract insects in pest management and control. At the same time this can be used to trap and kill or to trap and study such insects. Acoustics can be applied in the farm field or in the crop storage after harvest. Attraction depends on environmental factors like light and temperature. Insects can be detected by crawling, flying and their movements. To trap the insect signal to disrupt vibration communications can also be applied in case of mating. Attenuation in acoustics affects the result obtained and the cost of using acoustics proves more expensive than using insecticides. The use of acoustics to trap insects can be improved by proper timing and frequency study of the sound pattern of the insects. The attraction depends on time and segments of insect's specie. In case of mating, the use of high intensity of sound can drive away the female or male in the process, so proper study is needed to the use of time and sound patterns to match patterns of the target specie. Colors can be used as extra means of attraction and counting of the insects can be another added feature. In general, trapping, behavior manipulation and repelling are considered as the aspect of acoustic technology applications in insect monitoring [6].

A simple and low cost technology is required for detecting and quantifying insects. Insects can be detected from their sound or vibration of communication or movements. Field test was carried out to detect white grub and weevils using accelerometer and microphone systems at a distance of 20-50cm. Precise detection of soil pest is limited by attenuation and lack of specific feature in the broad band spectrum, but spectral templates are made for insects. Insect pest caused lots of damages to plants, like the grubs that are hidden in soil and so the farmers need cost effective method of monitoring these insects pest. Acoustic sensors are non destructive method of identifying the insects. Acoustic techniques depends on depends on signal to noise ratio and attenuation through the soil. It depends on sound made by insects and the duration. Attenuation is greater in soil than in air (~600 dB m1, compared with ~0.008 dB ml). However, there is evidence that low frequency sounds (<5 kHz) traveling through sandy soil can be detected over distances of 5–50 cm and sounds from plant up to 8m. Portable accelerometer and microphone were used to study acoustic range detection and to develop spectral templates to distinguish sounds by Phyllophaga (white grubs), Diaprepes (citrus root weevils), Scapteriscus (mole cricket), and other pest insects and from background noises (airplanes or automobiles) or sounds made by non–pest insect organisms (e.g., millipedes or earthworms). Accelerometer method: sounds were recorded from soil under orange trees, the trees were seeded with neonates and Sounds from infested and not infested trees were recorded 6 times over a 3–month period. Steel was driven into the soil and accelerometer was attached to it magnetically. The recorded signal for 3 minutes was passed to a charged amplifier, to a digital audio tape recorder, amplified 10-20db, band pass filtered between 2-3000Hz and digitized at 25 kHz. Spectrum templates were constructed by listening to the recorded sounds from trees. Soil Microphone: Turf insect and mole cricket sounds were recorded by a soil microphone at different locations. The signal processing was same in accelerometer with band pass filtering at 10-10kHz and with a broader range of sensitivity than accelerometer. Templates were constructed from the recording at sites for white grubs, earthworms, earwigs, millipedes, carabid beetles, or ants and the mole cricket. Another template is for the background noise. 30-200 sounds were used for construction of each template. The Accelerometer recorded sounds of the insect (neonates) and distinguish it from background noise of 300Hz to 0.7 and 1.1 kHz of the insect recordings. The sound from the turf insect was distinguished from the noise by a contribution of 400Hz from the turf sound in the soil microphone that was used in the study. Louder sounds from background were difficult to distinguish because of their components above 400Hz. The power ratio of the signal components was used to distinguish with the background noise and same was used to distinguish with other insect or organisms. Spectral was made for other insects and these insects cannot be distinguish from each other reliably than from background using spectral templates, because movement sounds of insects are present and not used for communication. Therefore, in acoustic detection, there is need to distinguish between pest and non pest insects or organisms and their density. A possible solution is to use dual microphone or accelerometer to identify exact location of source and to examine it temporal pattern. It is possible to identify features of this signal to distinguish them like slithering of Earthworms. Dual microphone or accelerometer system gives number of insects within range of sensors. The accelerometer is more delicate than the soil microphone with a sensitivity of 0-3kHz and further work is done to know total range of detection by acoustic sensors. Trained listeners will get acoustic evidence; identify insects by distinctive spectral and temporal patterns and to avoid destructive digging of samples. If insects cannot be identified precisely, exact location can be sampled [7].

3. WSN Prospective concept and approach.

The concept of white grub detection will be executed based on the combination of CO_2, volatile compound and acoustic sensor systems to support each other for precise and accurate determination of exact location and infestation of white grubs under the soil. The soil or environmental conditions that influence the activities of these grubs such as temperature, humidity, soil moisture and soil PH will also be measured all to aid in studying the behavior and habitat of these grubs for better detection and control.

3.1. Volatile compound sensor system

This sensor system will use the idea of foraging cues used by Entomopathogenic nematodes (EPNs) to locate host from the volatile emitted by roots of plants under attack. Evidence from studies have shown that at longer distance, EPNs used the specific emitted volatile to locate host (attracted to the volatile) and this idea of attraction towards the specific volatile can be used such that the volatile can be sensed or detected to indicate the presence and location of grub. Therefore, the plant root produced signal as a more specific root volatile in combination with CO_2 as an attractant would be more attractive than either alone and can be stronger means of detecting the grubs presence with a volatile compound sensor. Chemicals emitted from host are good host location cues. The CO_2 sensor for detecting the grubs is unreliable due to presence of the CO_2 released by other organisms in the soil and posed a difficulty in quantifying it from the host alone. The idea of a generic signal in combination with more specific signal can be a highly effective way of finding host and resources.

Volatile are emitted in large amounts by plants under insect attack. Studies have shown that EPNs were attracted to roots of plants after damaged by weevils and was found not attracted to the larvae of the weevils. This is a strong indication of influence of emitted volatile (below or above ground) for host location and presence. The roots only emit volatile when they are under insect attack.

A better understanding of how EPNs locates host insect can help to develop strategies to augment their efficacy in controlling soil pests (Turlings et al. 2012). Host detection can be more successful with a chemo-sensory apparatus.

The induced plant volatile and the CO_2 synergistic-ally are strong enough to detect the host insect. Diffusion rate of these volatile from roots is affected by the soil type, soil texture, humidity, soil PH and presence of organic matter, in which volatile travel in gaseous phase. All these influence the diffusion of host location signals and a better diffusion will improve detection. The genetic transformation of the plants will improve the signals from the plants and also the diffusion in the soil. Increasing evidence suggests that root produced signals can play a key role to detect the plants under attack by insect using a volatile sensor.

Chemiresistor sensor can be used at early stages, which has a poly3-hexylthiophene (P3HT) active thin film layer for the detection of insect infestation. Volatile compound is emitted by plants when attacked by insects and is detected by the thin film layer of P3HT due to the reaction of the thin film with vapor of the volatile compound; it causes increase in the resistance of the sensor. Then a threshold is used to indicate insect detection. Specific volatile compounds that were studied include; (*E*) –β – caryophyllene (sesquiterpene), dimethyl disulfide and β- copaene.

3.2. CO_2 Sensor system

The concept of CO_2 sensor system to detect white grub is based on the idea of EPNs foraging cues towards the host (the host emits burst of CO_2). The CO_2 sensor system detects the burst of CO_2 below the ground, but is difficult to quantify the actual quality of CO_2 from the grubs. Manually only the beetle and 1st instar stage of larvae can be destroyed by insecticide which is less harmful than 2nd and 3rd instars.

In earlier studies, ATMEGA 16 micro controller with BASCOM programming language, CO_2 sensor (MQ-135), soil moisture sensor and PH sensor with Global Positioning System (GPS-L80), Global System for Mobile Communication (GSM - SIM 800), display (LCD) and Serial to USB converter are the peripheral components. White grubs appear at monsoon, soil PH and moisture have changed. System at field with sensors buried, as MQ-135 detects high level of CO_2, a message is indicated on LCD. The message is exact location of insect via GPS module and send to farmer's mobile number in the SIM 800 module. Location is recorded in longitude and latitude and interpreted using Google.

The MQ-135 used to detect burst of CO_2 by grub at 2^{nd} and 3^{rd} stage of instars mainly. EPN is natural enemy to white grub, is attracted by CO_2 burst from grub and soil moisture, temperature, humidity sensors are employed to check the environmental conditions for early (1^{st} stage) infestation period of white grubs life cycle in the seasonal cycle.

The quantification of CO_2 is difficult because of presence of other organisms in the soil that contribute to the amount of CO_2 as part of soil respiration. Quality of the CO_2 will be negatively associated for the white grub. CO_2 concentrations have different relevance to animal species based on location. Insects like bees, ants and termites in their living place have CO_2 concentrations far above the atmospheric concentration of 0.038% (380 part per million (ppm)) because of their large number in an enclosed space. (CO_2 concentrations inside bee hives have been measured at over 4% (40,000 ppm) (Seeley, 1974), levels in termite nests range between 0.3–15% (3,000–150,000 ppm) (Ziesmann, 1996) and Ants take advantage of this effect when they are outside their nests and use CO_2 seeping from the nest entrance to find their way home (Buehlmann et al., 2012). These CO_2 concentrations can be taken advantage of to detect the presence of the white grubs especially in large number if a chemical attractant can be placed to attract them and get them in large number at a place (high density).

Recently, a nano material is used as attractant of pheromone on septa as insect trap for the adult beetle (male) to appear in large number (high density), the nano material allows the trap to stay longer for 15 days against 1 day. Action will be taken to control the high density of the male adult beetle. With this, the new cycle (eggs) of the beetle will be stopped after destroying most of the male or female adult and is effective in resource use of insecticide at a single location with their large number.

3.3. Quantification of CO_2

Measurements of gas in the environment or safety applications are measured in terms of concentration values e.g. calibrated concentration values in parts per million (ppm), but for sensors related to measurements in other values e.g. conductance, the conductance values need to be calibrated to the concentration values. The calibration is done in a chamber where concentration is kept constant and then gradually increased. Exponential map is obtained for the concentration levels against the conductance changes estimated or the use of artificial neural network.

The disadvantage of the calibration above is when used in an open environment; the sensors are exposed to fluctuating concentration levels and environmental conditions (temperature and humidity) affects the sensor response. The work by (S. De Vito et al.) addresses the problem of gas quantification in an open environment for urban pollution [8]. The calibration of sensors was done with data from outdoors over a long period of time. There are sources of uncertainty and an estimate of its prediction will be important. Figure 1. below shows CO_2 and temperature relationship [9].

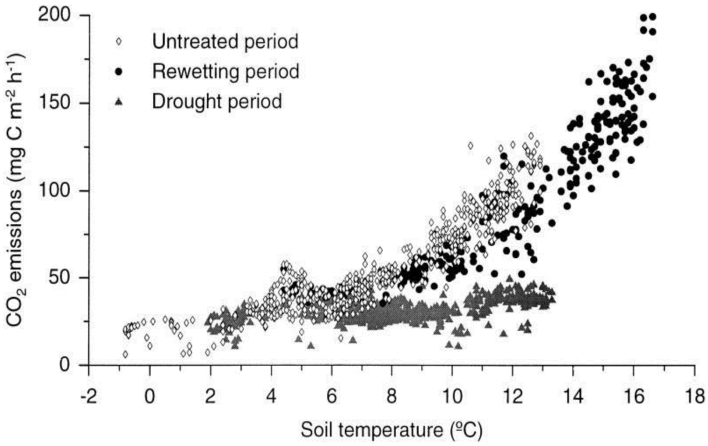

Fig. 1: CO_2 versus soil temperature.

3.4. Acoustics sensor system

The acoustics systems was studied and presented mostly by entomologist who applied the technique of trained listeners to establish the presence of white grubs from the sound of their activities in the soil. The system was built with soil microphone, audio tape recorder, digitizer, filters and spectrum analyzer (spectogram or oscilloscope) or by headphone. A lot is done by an expert (Richard W. Mankins et al.) for so many years to establish spectral templates for different insects as an entomologist in USADA (United States of America Department of Agriculture).

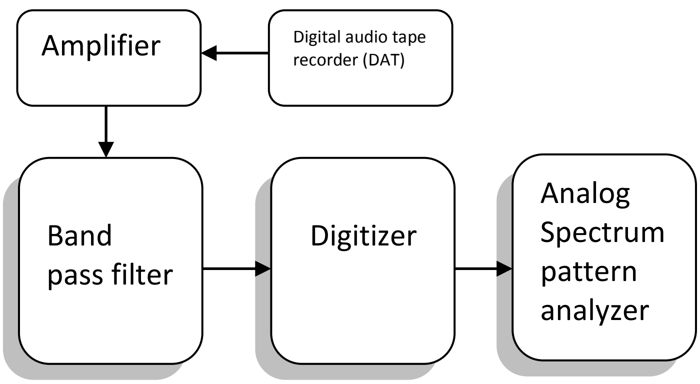

Fig. 2 Audio Master Kit (on-site) and sound analysis for frequency pattern (off-site).

To establish a spectral template for the presence of white grubs depends on electronic factors (attenuation and distortion) to environmental factors (soil type and structure). The system involves examining recordings from the field and ratings (low, medium and high) as compared to different techniques employed for observations in the recordings (sound pulse and listener) including excavation technique (cup-cutter). Figure 2. above showed the method employed by entomologist. The figure 3. below shows the graph of soil sound with respect to temperature and its attenuation.

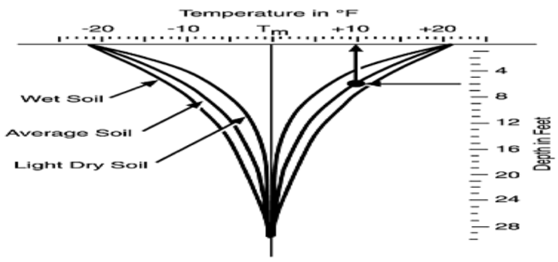

Fig. 3 The effect of temperature on attenuation of sound.

4. Proposed concept

Since the CO_2 system is considered as a generic signal to be detected from the activities of white grub, which comes from the idea of foraging cue of nematode (white grub natural enemy), is unreliable and has to be combined with a specific signal or other non destructive technique. In this case we shall combine volatile detection from roots of plants under insect attack as a specific signal with CO_2 detection or with acoustic system. The whole three (3) sensors system can be combined for precise detection.

4.1. Frequency pattern of sound monitoring by acoustics

Acoustic system with a soil microphone will be inserted in the ground and sound frequency pattern will be displayed by the help of *LabVIEW,* continuously monitored to observe the temporal pattern of the sound to indicate the likelihood of white grub infestation. All of this will be conducted in the lab, then to the greenhouse and to the field. The period of less background activity contributing to noise will be considered, at the same time with the best period of white grub activity. The other parameters are to monitor condition of the environment including CO_2 due to soil respiration that are present for white grub activity. The real time monitoring of frequency pattern of sound via *LabVIEW* as graphical representation will make it easier rather than listening to rate likelihood of infestation. Figure 4. shows example of spectral and temporal pattern below [10].

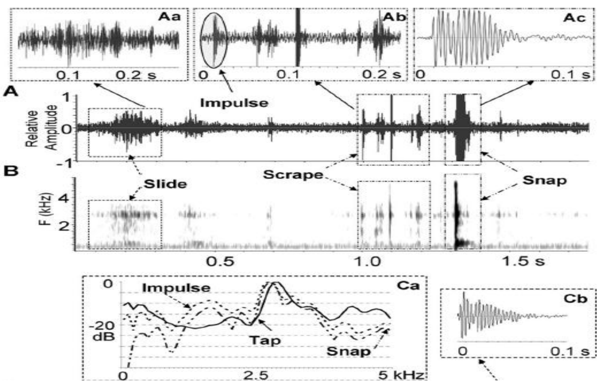

Fig. 4 Spectral and temporal pattern for insect infestation due to activity of insect.

The table 1. below, is the comparison between other methods of managing insect pest and WSN.

Table 1 The comparison of control and monitoring methods.

Pest control methods	Cost	Eco-Friendly	Health of human	Quality of product	Man power 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

5. Conclusion

Initial stage detection of these insects life cycle is required for accurate time and location for control of these insect pests for resource effectiveness. This location can be communicated to a mobile phone via Global System for Mobile Communication and Global Packet Radio Service modules.
The co_2 sensor for detecting the grubs is unreliable due to presence of the co_2 released by other organisms in the soil and poised a difficulty in quantifying it from the host alone.
LabVIEW, continuously monitor to observe the temporal pattern of the sound to indicate the likelihood of insect infestation. All this will be conducted in the Laboratory, then to the green house and to the field. The real time monitoring of frequency pattern of sound via LabVIEW as a graphical representation will make it easier, rather than listening to rate likelihood of infestation.

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References

[1] Glenes Concepta D'Mello and Rashid Hussain, "WSN Controlled Insects Monitoring: Identification of Location of White Grub," International Journal of Current Advanced Research Vol 5, Issue 7, (2016), pp 1078-1081.
[2] Ted C. J. Turlings, Ivan Hiltpold, Sergio Rasmann, " The importance of root-produced volatiles as foraging cues for entomopathogenic nematodes," Springer Science+Business Media B.V. 2012.
[3] R. W. MANKIN, M. T. SMITH, J. M. TROPP, E. B. ATKINSON, AND D. Y. JONG, "Detection of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) Larvae in Different Host Trees and Tissues by Automated Analyses of Sound-Impulse Frequency and Temporal Patterns," J. Econ. Entomol. 101(3):(2008), 838-849.
[4] Richard W. Mankin, Barukh Rohde, and Seth McNeill, "Vibrational duet-ting mimics to trap and disrupt mating of the devastating Asian citrus psyllid insect pest," Proceedings of Meetings on Acoustics, Vol. 25, 010006,(2015).
[5] Minling Zhang, Robert L. Crocker, Richard W. Mankin, Kathy L. Flanders,Jamee L. and Brandhorst- Hubbard, "Acoustic Identification and Measurement of Activity Patterns of White Grubs in Soil," J. Econ. Entomol. 96(6): (2003), 1704-1710.

[6] R. W. Mankin, "Applications of acoustics in insect pest management," CAB International (2012), 1749-8848.
[7] Richard W. Mankin, Clayton W. McCoy, Kathy L. Flanders, Jamee Brandhorst, Robert L. Crocker, and Jeffrey P. Shapiro, "Methods for Acoustic Detection of Insect Pests in Soil," Proceedings of the Soil Science Society of America Conference on Agro-acoustics, Third Symposium, 36, (1998), Buoyoucos, MS (3/31/2016).
[8] V. M. Hernandez bennetts, " Mobile Robots with In-situ and remote sensors for real world gas distribution modeling," Orebro University, ISBN 978-91-7529-055-3, (12/2014), pp. 22-23.
[9] J. LLOYD and J. A. TAYLOR, "On the temperature dependence of soil respiration," Functional Ecology 8, (1994), 315-323.
[10] R. W. Mankin, A. Mizrach, A. Hetzroni, S. Levsky, Y. Nakache, and V. Soroker, "Temporal and Spectral features of Sounds of wood-boring Beetle Larvae: Identifiable patterns of Activity enable improved discrimination from background noise,(Sounds of Wood-Boring Beetle Larvae)" Florida Entomologist, 91(2): (2008), 241-248.