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WSN application for crop protection to divert animal intrusions in the agricultural land

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ABSTRACT

Crop damage caused by the animal attack is one of the major threats in reducing the crop yield. The farm areas near the forest edges are prominently affected by the wild animal attacks. This paper presents the development of a Wireless Sensor Network application for Crop Protection to divert animal intrusions in the crop field. The nodes in the crop field are equipped with PIR sensors, sound generating devices, light flashers and RF module. For early detection of the animal at the perimeter of the farm intrusion detection system is installed. Animal entry at the farm boundary is detected by the nodes fixed at the boundary and is communicated to the central base station. The sequence of the node activation is location based, time based and proximity based. On receiving this information the nodes in the vicinity of the animal activates the deterring gadgets and diverts the animal away from the field. A Graphical User Interface has also been made to indicate the status of the field conditions.

1. Introduction

The result of rising global population has led to higher food production demand. Farms are always under threat of attacks from various animals, insects and birds. Due to the expansion of cultivated land into previous wildlife habitat, crop raiding is becoming one of the most common conflicts antagonizing human-wildlife relationships (Veeramani et al., 2004). On the other hand, one of the main challenges facing wildlife conservation in the twenty-first century is the increasing interaction between people and wildlife and the resulting conflicts that emerge. Crop fields specifically in the proximity of forest area, the issue of wildlife animals entering and destroying crop field has taken a major crisis situation. The total yield in the farm is reliant on how the crop is secured from the external attacks from insects, birds, animals and other intruders causing damage to the crop. Crop-raiding animals may cause substantial damage to agricultural crops, and this has always been a major issue of contention throughout the world (Foster et al., 2000; Maxwell, 1892).

Automated systems are part of the agricultural processes leading to high yield and maintaining good quality of the crop. These systems are easily available and adaptable by the farmers. Wireless Sensor Networks (WSN) has been emerging in the last decade as a powerful tool for connecting the physical and digital world. They can be used in challenging locations where it is inconvenient for human to be present (Garcia-Sanchez et al., 2010, 2011; Felemban, 2013). Wireless Sensor Network based designs have been largely exploited in the last decades for the solution of several real world problems, ranging from environmental monitoring to advanced wireless localization services (Viani et al., 2016). Many Wireless Sensor Networks are used to monitor and understand the wild animal behavior (Millspaugh and Marzluff, 2010). WSNs have been used for various applications including habitat monitoring, agriculture, nuclear reactor control, security and tactical surveillance (Polastre et al., 2004). Researchers have reported a well developed and tested Wireless Sensor Network for the detection of wildlife crossing the roads and giving alert signals to the vehicles in order to avoid mishaps on the roads. Doppler radar technology has been used along with a WSN platform to achieve a low cost and scalable solution of the problem (Viani et al., 2014). Virtual fencing, radio tracing, various sensor architectures and low cost wireless sensor technology and along with UAV mobile node is used in the application of animal monitoring and related environmental control. (Rovira-Mas, 2010; Rains et al., 2011; Bishop-Hurley et al., 2007; Millspaugh and Marzluff, 2010; Polastre et al., 2004; Xu et al., 2010; Polo et al., 2015; Wang et al., 2006; Tetarave and Shrivastava, 2012; Ojha et al., 2015). Zigbee based Wireless Sensor Network are used for monitoring animals (Huircán et al., 2010; Keshtgari and Deljoo, 2012). In most

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of the protection techniques diversion of animals from the crop area is not given more thought and the existing techniques many a times can be harmful for the animals leading to disturbance in ecological balance.

The focus of the proposed system is to create closed loop animal intrusion detection and deterring system, which is capable of sensing, reporting and taking preliminary prevention actions in an automated manner. To make the system more cost effective, a set of sensors and related gadgets are identified and used in the Wireless Sensor Network development process. The challenges for this system take account of use of appropriate Sensor Nodes, distance estimation and sleep strategies of nodes for maintaining their efficiency, as well as keeping it scalable for any size of the farm field. The foremost concern of this research contribution is the application of the WSN and use of technology assisted upgrades to achieve crop protection without hurting the animals and diverting them in appropriate way towards the cover crops to avoid their starvation.

The paper is organized as follows. In Section 2, the issues of wild animal attacks and their effects are briefly discussed. The functional description of the proposed system is discussed in Section 3. Then, the architecture of the proposed network and related algorithms will be discussed in Section 4 along with design considerations. The results and discussions are covered in Section 5 and finally the conclusion is stated in Section 6.

2. Issues and concerns of wild animal attacks

As a result of the socio-economic activities in certain areas, forest cover has been reduced leaving the animals with smaller habitats and less food. So the wild animals have resorted to feeding on crops in farm fields, resulting into a conflict. Human beings want survival while wild animals need the same. This has brought about confusion and resentment from both sides rendering conservation and preservation a challenge, hence need for interventions that reduce crop raiding to enhance ecological, economical and social sustainability so as to foster co-existence. Starting from seed selection, soil preparation, irrigation, cultivation to harvesting process different technologies have been used by the farmers. Animals and birds attack the crop field and inadvertently damage the crop at different stages right from seed level to the ready crop. It is reported that these wild animals attack the farms located at the forest edges. Due to the scarcity of food in the forest area they enter the crop field boundary and damage the crop. Researchers have reported that White-tailed deer (Odocoileus virginianus) may cause more damage than any other species of wildlife. These damages include crop losses, automobile and aviation collisions, disease transmission, environmental degradation, and destruction of ornamental plantings (VerCauteren et al., 2006). Crop damage is the most prevalent form of human-wildlife conflict across the African continent. The occurrence and frequency of crop-raiding is dependent upon a multitude of conditions such as the availability, variability and type of food sources in the area, the level of human activity on a farm, and the type and maturation time of crops as compared to natural food sources. A wide variety of vertebrate's conflict with farming activities in Africa. These include birds, rodents, primates, antelopes, buffalos, hippopotamuses, bush pigs and elephants (Human-Wildlife).

Table 1 shows the crop damage caused by various wildlife species in Kerala (India) and through the survey made by the researchers at different villages shows that the crop damage caused by the wild animals is prominent and costing large financial loss (Jayson, 1999). Table 2 shows the crop damaged by different animals reported at Central Italy (Amici et al., 2012) and parts of Nepal (Awathi and Singh, 2015).

Table 1
Percentage crop damage by wildlife to different crops in Kerala (India) (Jayson, 1999).

Wild animal	Crops	Percentage crop damage
Elephant	Coconut, plantain, paddy	72
Gaur	Mulberry, sandal	62
Sambar	White sapota	17
Wild boar	Tapioca, tubers, paddy	16

Table 2
Crop damage caused by wild animals: Italy (Amici et al., 2012) and Nepal (Awathi and Singh, 2015).

Animal causing the damage	Crop damaged	Percentage crop damage
Wild Boar	Cereals (maize, wheat, oats, Barley)	46.48
	Vineyards	13.71
	Durum wheat	13.84
	Hazelnuts	12.92
	Grassland	11.62
	Sunflower	8.62
	Chestnuts	3.26
Monkeys, Porcupine, Goral, Deer, Bear	Maize	38.90
	Potato	29.60
	Millet	18.60
	Wheat	6.70
	Paddy	3.80
	Pulses	0.23

The problems associated with wildlife include:

- destruction of crops,
- destruction of farm infrastructure,
- creation of an environment of fear,
- loss of human life,
- injury to human beings.

The issue of wild animal attacks on crop fields is becoming a very common phenomenon all over the globe. There are several traditional methods applied by the farmers which include use of Scare-Crow, Hellikites, Balloons, Flyers, Shot/Gas guns, String & stone, etc. Nylon nets are used by some farmers to cove the whole farm area but it is a not economical solution, though it is full proof. Also, its lifetime is short and has high maintenance cost. Some farmers use traditional techniques such as wire fencing, bush fencing, Dog guarding or manual guards to protect their crops from animal attack. In their quest to protect their crops against wildlife raiding, farmers utilize strategies that are often cruel and ineffective. While arbitrary killing or trapping of suspect crop-raiders may provide a short-term solution to the perceived problem, it fails to address the long-term needs of either farmers or wildlife. For example captured animals are frequently taken at random and their removal often has little effect on the level of crop damage.

Technology assistance at various stages of agricultural processes can significantly enhance the crop yield. There are traditional and Non-traditional techniques used by the farmers to protect their ready crop from the animal attacks (Bishop-Hurley et al., 2007). Habitat and environment monitoring represent a class of sensor network applications with enormous potential benefits for scientific communities and society as a whole. Sensor networks represent a significant advance over traditional invasive methods of monitoring (Tiedemann et al., 1999). Garcia et al. addresses some problems including animal classification, detection and tracking their positions. It is reported that targets detection is carried out by a PIR sensor and camera sensors. Tiny motes are deployed in order to get information about the animal presence (Garcia-Sanchez et al., 2010).

One of the key advantages of Wireless Sensor Networks (WSN) is their ability to bridge the gap between the physical and logical worlds, by gathering certain useful information from physical world and communicating that information to more powerful logical devices that can process it (Bishop-Hurley et al., 2007). WSN can in due course minimize the intervention of human in variety of applications. Thus, there is need of a technology assisted crop protection system which will be cost effective robust, reliable and easily adaptable by the farmers.

3. Functional description of proposed system

In the proposed crop protection system, the first issue to be addressed is the detection of entry of the animal in the crop field. Fig. 1 shows the crop field layout and the placements of the wireless sensor nodes in the field. At the boundaries of the crop field wireless sensor nodes will be placed at the corners of the field which will detect the animal entry using a laser assisted perimeter guarding sensor. At the center of the field the Base station node is located which will note the entry of the intruder and accordingly activate the nodes in the vicinity of the animal. According to the area of the farm, several wireless sensor nodes will be deployed at strategically chosen locations in the rest of the crop field. The range covered by the individual node and the total area of the crop field will decide the number of nodes to be deployed in the field.

The sensors placed on the nodes will locate the animal presence and divert it by activating flashers and sound devices based on the location, time and proximity. Even when the animal bypasses the boundary level alert and somehow enters into the crop field, the PIR sensors on the system nodes will identify their presence and activate the deterring gadgets and force them to come out of the crop area and divert them to a buffer zone, where there would be sufficient food for them. This would save the precious crop and prevent starvation of the animals, thus help maintaining ecological balance. The nodes in the neighborhood of the attack zone at the boundary will be activated by the central node and all other nodes in safe area are set in sleep mode in order to save power.

4. System architecture and programming

The focus of this system is to create a closed loop animal intrusion prevention system, which is capable of sensing, communicating and taking preliminary deterrence actions in an automated mode. Here, a detector system is used which actually alarms if any intrusion occurs. Fig. 2 shows the main components of a Crop Protection system of a single node.

During the initialization, the central node of the system localizes all the nodes. The information that a particular node resides near with fixed or anchor node is sufficient. Then the system shifts to a wait state. Any intrusion at the boundary of crop field is detected by an array of opto-interrupters and is reported to central node. Once such intrusion is detected, the central node uses distance estimation data to identify which mobile nodes lie near the intrusion area. The central node then selects several of these nodes at random. This selection also includes a parameter that a node with low battery level would be selected for a short time or never selected. After the node selection, the central controller sends them an action command. At the same time, it also informs the caretaker node present on a farm field about the intrusion. During this, if any outward intrusion is detected, the central node should send stop command to all other mobile nodes. The foremost focus of all the commands of central controller is on power saving. Thus, a central node is also responsible for defining a sleep strategy tailored to our needs.

Mobile nodes equipped with a sound source and flashers are activated based on the intrusion location. Besides this, a node is also responsible for forwarding any other nodes data to and from the source. The mobile node is also responsible to monitor its battery level. If the level falls below a prescribed value, then the node should inform it to the central controller. This process is continued until a stop command is received from central controller.

Finally, a system also has a caretaker node that is held by the owner or caretaker of the farm field. The caretaker node is also equipped with a sound buzzer and a LED indication and is responsible for notifying the caretaker about the intrusion.

The caretaker node informs the central controller about its location once it is present near crop field. So that a stop command can be initiated. This can be implemented by the caretaker through a switch on the node, thereby acknowledging the intrusion. Throughout the development process, the implementation of this system is based on two key principles: Low cost and easy adaption by the user.

The core need of operation of this system is the spatial area fixation of nodes, which is achieved using a modified distance collection approach based on the matrix logic theory and its postulate

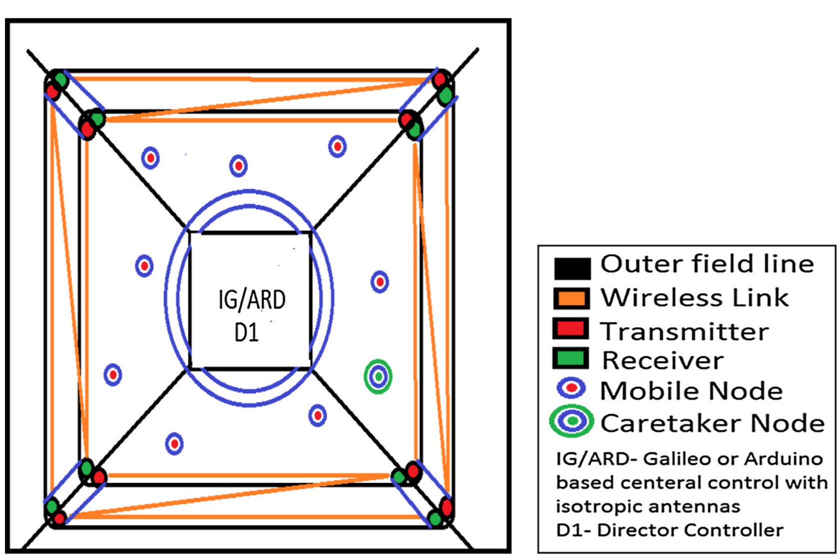

Fig. 1. Node deployment layout for the crop protection system.

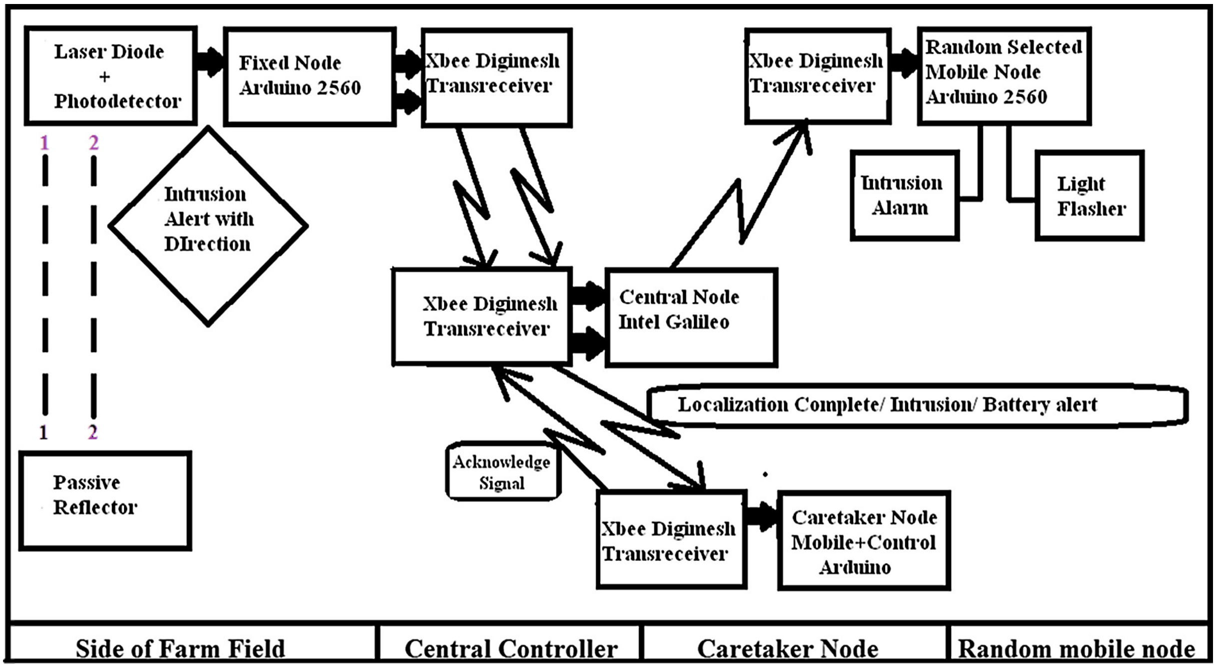

Fig. 2. WSN based crop protection system block diagram.

(Foster et al., 2000; Maxwell, 1892). The practical implementation of this approach is done through special frame format that is useful for communicating distance collection data as well as system operation commands. The development of this system follows concurrent approach because of the three different types of nodes. The intimation of intrusion and control for caretaker has been provided through Graphical User Interface (GUI) developed using MATLAB.

4.1. System hardware

System operation basically includes the activation and deactivation of nodes depending upon the status of intrusion at a particular location. In order to maintain a uniform programming approach, this system uses same frame format as that of the distance collection frames to communicate activation and deactivation of nodes. The process of detecting an intruder can be at Boundary level node (due to intrusion from crop field edge), or at Mobile node level (due to motion detection). The layout of the system operation is shown in Fig. 3.

A direction sensitive Opto-interrupter using two Laser sources, large surface area photo-detectors and control electronics is developed to form a boundary level Intrusion detection system. Here the sound signal generated will be in audio frequency range. The animals have fear of light flashes and sound alarms. However it is to be noted here that there has to be variation in the pattern of sound signal as well as light flashers since the animals very easily habituate to the repeated signals and then they ignore these gadgets. In this research work, the time period of light switching is chosen to be the parameter of variations, and the parameter is selected at random out of an array defined within interval of 400–1300 msec. The random nature opposes the animals getting used to same time period of flash and sound. The nodes at the boundary of the crop field are fixed on the aluminum posts. Laser diodes and detectors are fitted on these posts. Farmers are generally aware of the animals attacking on their crops and once the animals are known the laser diode and detectors can be fitted on these posts at a level adjustable as per the animal size. There is arrangement made on the posts to shift the Laser diode and detector assembly. The range of the laser diode used in the prototype is 100 m which can be extended to few kilometers by using high power laser diodes. The user is given a facility to make the system automatically ON during the dark (night time). Laser diodes are preferred in this research work since they can cover more distance as far as the perimeter control is concerned. Laser diodes are available with a compact design and they can be packaged appropriately to make the assembly more robust.

System currently uses 6 V 4.5 Ah rechargeable battery as power source and supports charging by both power adapter and solar charger. System is usable till charge reaches 4.75 V. This generates an interrupt which in turn sends power notification to central controller. The central controller then removes such node from the database of active mobile nodes and issues a warning on interface display to charge particular node. Power savings is assisted by sleep modes, wherein every mobile node and final edge node goes into sleep as long as there are no requests to serve. Also, solar panels are used to charge these batteries. Fig. 4 shows the components of the node used in the system.

For complete system operation, it is necessary to know the direction of movement of the animal during intrusion. The entry of the intruder from outside of the field area into the crop field or vice a versa can be detected using this direction sensitive Opto-interrupter which is further conveyed to the central node. To implement this setup effectively in real-time, the strong interrupt structure of AVR microcontroller is used.

Current hardware setup has the following features to summarize:

a. **Mobile Nodes and final edge node**

Arduino platform is selected as it facilitates rapid prototyping and lower development costs. Arduino MEGA 2560 dev. Board is used as mobile and edge node processing unit. The base reason of avoiding cheaper Arduino Uno is that the programming takes up 1432 bytes SRAM during compiling the code. Using this code on Uno creates serious processing stability concerns due to 2000 Kb SRAM.

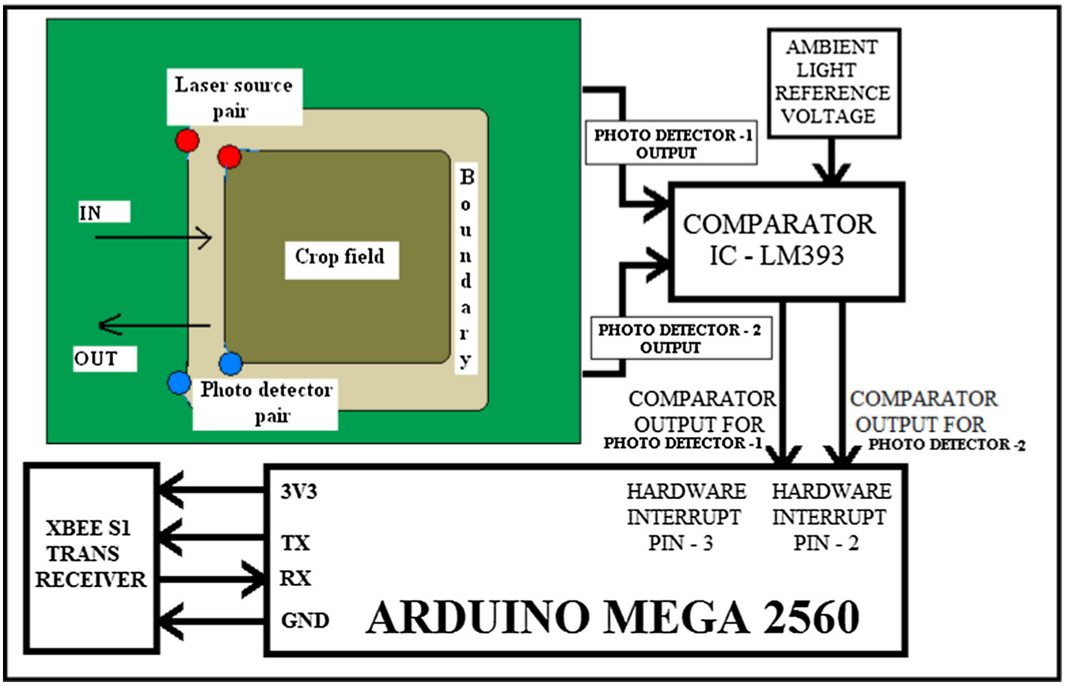

Fig. 3. Intrusion detection mechanism of final node.

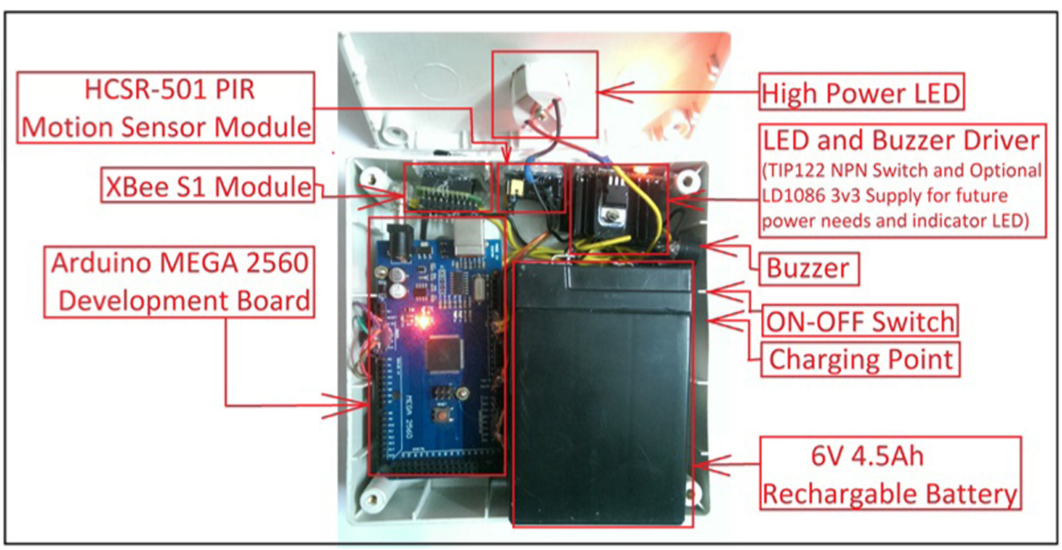

Fig. 4. Components of the mobile node.

b. **Central node**

Intel Galileo is used as central node. While the central node programming is usable on MEGA 2560 board, the localization data from multiple nodes practically slows down the AVR controller. Intel Galileo with its quark x1000 32-bit SoC running at 400 MHz provides more processing speed. Besides, the inventory availability is another reason.

c. Prototype system uses 405nM LASER diode (5 V, D405-120, US Lasers, Inc.) and 22 mm diameter OEM LDR. The higher diameter of LDR facilitates the alignment of LASER-LDR.
d. Mobile nodes use HCSR-501 passive infrared motion sensor to specifically detect the motion of animals near the nodes. These are set in non-retriggering mode to provide a interrupt to Arduino upon detection.

The system operation is implemented in two levels:

4.1.1. Perimeter crossing

Interrupt driven system is used to detect the direction of the movement of the animal or intruder. The hardware interrupt pins are set up in LOW state for interrupt mode and software flagging technique is used to detect direction of intrusion through Arduino. When the animal is crossing the boundary from outside field into the crop area an interrupt from the outer opto-interrupter will be generated first and will indicate that the intruder is entering the crop area. On the other hand if the intruder is already in the field and crossing the boundary then the inner opto-interrupter will be active earlier to the outer opto- interrupter. This will generate an interrupt which will indicate that the animal movement direction is from crop field to outer field area.

4.1.2. Proximity detection

The system operation cannot be kept solely dependent upon intruder movement along perimeter of the field, as it does not take care of all cases of intrusion. For example, suppose a herd of animals intrude in the field, the system will get activated, which is normal operation. However, if only one or two deer from the herd move out leaving the field, the system will falsely detect intrusion clearing and will be deactivated. To address such case, the mobile nodes are equipped with PIR sensor capable of detecting animal movement. The PIR module has been configured in non retriggering mode, so that it will produce a digital high output until a movement is detected, or timeout reaches after movement is stopped. This output is given to Arduino interrupt, which is configured for capturing interrupt on rising edge. When an interrupt is generated, the ISR first finds if system is available and whether the activation request has not been sent previously, with the help of software flags. If these conditions are met, then it sends forced activation reply to central node. Thus, the nodes remain activated.

Additional Programmed Features

A unique set of features that make the system stand out towards optimized and simplistic use of the hardware includes:

1. **Mesh networking and random deployment:** The WSN motes used to communicate information are connected using mesh topology. So, failure of any of the nodes does not affect overall function of the system. Additionally, number of mobile nods can be added or removed from the system as per the size of crop field.
2. **Random activation:** The master node program has ability to choose a new subset of nodes every time the intrusion occurs in a particular area. For example, if intrusion occurs from one side, not all nodes within that area are activated, but only some of the nodes in that area are activated. The selection of these nodes is random every time. The Light and sound gadgets are activated on different nodes every time so that the intruder does not get habituated to the system.
3. **Random source pattern:** This feature adds more diversity to the random nature of the system. In this feature, the code chooses a pattern randomly in which the light and sound sources will activate. This again helps to maintain system's armed operation by making sure that the intruder does not get used to same light or sound pattern.
4. **Selective sleep:** This feature is important from point of view of mobile nodes. The selective sleep feature is implemented in two different ways for the final node and for mobile nodes respectively. For final node, the sleep routine runs such that it can respond to a new UART data as well as on interrupts while, the mobile nodes employ more dynamic pattern. Here a node goes to sleep if it is not selected to activate against intrusion. It is awake for rest of the time to respond to any distance collection or system requests. For additional power saving, the sleep function also shuts down on-board ADC, timers and communication buses.

The implemented laser fence and sensor technology is first detecting the presence of an animal with smaller size (with 15 cm Height and above) to a larger size animal. This system does not focus on insect or tiny pests. There should not be presence of any plants or grass in front of the laser fence which unintentionally will block the communication link between the Laser source and the detector. Intrusion detection is achieved first with the set up correctly and then accordingly the alert message is send to the Central node. Further the central node activates the local node in the vicinity, at the same time the PIR sensor on the local node detects the presence of the animal and activates the sound and visual scaring gadgets and diverts the animal away from the main crop area. The node activation is formulated in such a way that the animal is diverted away from the crop area. With this type of a system there is no injury caused to the animals and the ecological balance is maintained appropriately. Efforts are taken to make the system as cost effective as possible and robust to withstand for all sorts of environmental variations.

4.2. Programming details

For the sake of reliability and faster processing, the distance collection approach uses a frame format for communication amongst the nodes. As shown in Fig. 5, starting from the left is the flag character. A flag character in DCUB (Distance Collection using Uni-hob Broadcasting) frame indicates start or end of the flag space. It basically capsules the actual flag characters. It has no use as start indicator or checksum bit; rather it is used to avoid confusion with String command's character acceptance mechanism making the first useful flag actually start from position 1 and not position 0. Next is the Request type flag field. This field includes four types of requests covering distance collection as well as system requests. Its preceding field is the reply type field, which indicates whether a received frame is a distance collection frame or a system operation frame. The type of the node that generated the request, that is mobile node or final node, is indicated by the next 1 byte of frame. The frame ends by a flag character. For distance collection or activation reply frames, the node addresses are present after the end flag character.

The program flow starts at central node which initiates a primary distance collection request. A mobile node receiving this request replies to this with its own address. Then using AT commands, it sets its XBee in one – hop broadcast operation and broadcasts a secondary localization request. For every primary localization reply received, the central node creates a new database entry indicating new direction of spatial area. While for every secondary localization reply received, the central node searches for destination address string in complete database and adds MY address entry to the database where destination address entry is found.

If a mobile node receives a secondary distance estimation request from other mobile node, then it extracts a sender node ID from that request, creates a secondary distance estimation reply and forwards to central node. This process of creating and forwarding secondary distance estimation request is same similarly repeated. A mobile node is allowed to give secondary replies maximum up to 3 times, to avoid duplication of data and requests or overlap error.

Eventually, the request reaches end nodes. The end node is instructed to give only one secondary reply and it does not forward the request. When central processor node finds the end node request, it appends the end node address to the respective entry and finalizes that entry, implicating that no further additions can be made there. If the information from all nodes is collected in certain time, the central node only keeps the finalized entries and clears all other entry threads. Thus, at this stage, the system is said to have collected all distances along with their distance estimates, if included. Activation request is sent by central controller only. This has no relation with DCUB protocol; rather it specifically targets the operation of intrusion prevention system. When the central controller receives an activation reply from any of the final nodes or due to motion sensing at mobile nodes, the central node determine the node address that has send activation reply from that packet, and evaluates the nodes near it. It then creates a packet containing node addresses of those mobile nodes selecting them at random, and broadcasts this request to all nodes. When a mobile node receives activation request, it checks if its node ID is in

Flag Start	Request Type	Reply Type	Node Type	Flag End	Receiver ID	Sender ID
Z	R	P	N	Z	XX	XX

Fig. 5. Frame format for modified distance collection approach.

the request packet or not. If its ID is present, the mobile node activates the alarm circuit with random delays.

When a central node receives deactivation signal from any of the final nodes, it generates a deactivation request packet and broadcasts it to all nodes. The deactivation request is also, not the part of DCUB distance estimation protocol. When this packet is received, a mobile node turns off alarm circuit and the whole system returns to normal node.

The final node never generates either primary or secondary DCUB requests. It can just send replies to any of the primary or secondary distance estimation requests. When central controller receives the final node's distance estimation reply with receiver ID as final node's ID, and sender ID. The central node compares the sender ID from this request with complete database, and once the entry is found, it adds final node ID to that database string. It then finalizes that string, indicating that no more nodes can be added further.

5. Results and discussions

The Graphical User Interface for this system is developed using MATLAB. The GUI enables the user or Caretaker to observe the status of the active node and then a display for the nodes in the crop field is shown with appropriate activation of sensors and gadgets on the nodes. As shown in Fig. 6, the GUI for this system is user friendly and gives detail information about the situation in the crop field. A message regarding the intruder entry in the crop field is displayed. The sensor nodes present in the crop field have sound devices, flashers and PIR sensors. The motion of the animal in the crop field at certain location can be easily detected by the PIR sensor and corresponding node and gadget activation is displayed in GUI. The status of the nodes for various conditions is indicated with different colours. Additionally, a system reset facility has been provided for the caretaker to deactivate the system. The operation of the GUI can be summarized as follows:

Galileo board as a Central node activates the serial communication port and gets connected to one of the communication ports of the host computer. At this stage the user/caretaker will click the "Connect" button to activate all the nodes and the system will work autonomously. On reset, the system attempts to localize the nodes through distance collection approach. During this time, if an intruder animal attempts to enter the field, the final node experiences interrupt from interrupt detection circuit. The intrusion detection is indicated to the central node. For this intrusion, the central node randomly selects and activates nodes near the location of intrusion. A particular set of nodes are activated by the central node and if clearing signal is obtained then the system returns to its guarding phase. On reset, the system forgets current intrusion, and it again enters the guarding position waiting for next intrusion to occur. In order to turn off the system, a disconnect button is provided in connection settings which disconnects the interface from central node. Also, it gives a facility to prematurely deactivate the system, so that if there is an intentional movement of farmer or caretaker himself, then the system can be stopped from being active.

The prototype of the crop protection system was tested in the Laboratory using four mobile nodes, one boundary node and a central Galileo node. Fig. 7 shows the laboratory set up for the testing of the developed system. Initial testing was conducted on a board of 1 m × 1 m board and later the test was conducted on the open terrace of 8 m × 8 m.

An animal robot was used to verify the results of this prototype design. The working of the system was monitored for one side of the crop field. The robot has been programmed in order to move forward and backward in the test field. The placements of the end nodes were modified and the activation of the system was noted. The entry of the animal robot at the boundary of the test field was detected by the system and accordingly indicated on the GUI display. The sound and light flashers on the nodes in the vicinity of the robot were activated predicting its motion in the field. Thus, on the laboratory level the presence of the intruder is detected and

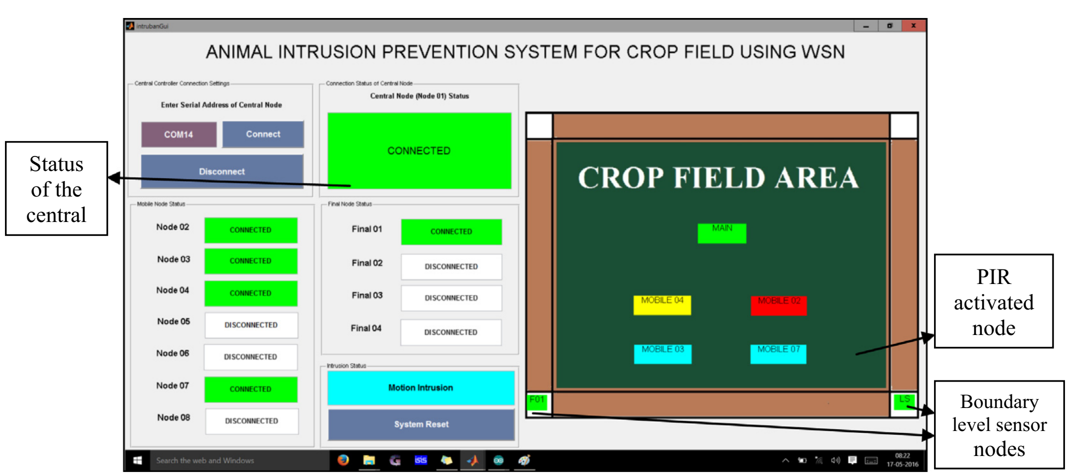

Fig. 6. GUI for the crop protection system.

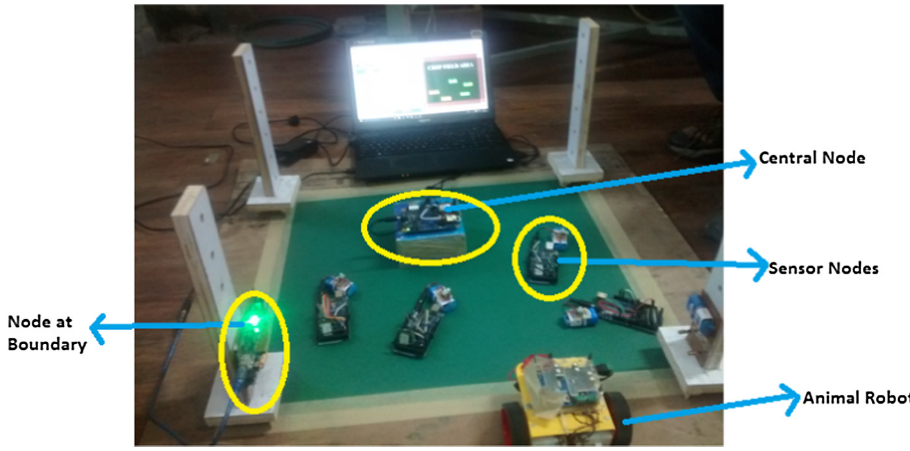

Fig. 7. Laboratory level set up for the WSN based system.

the consequent nodes in the vicinity activate the deterring gadgets in order to divert the intruder from the crop field.

After completing the tests in the laboratory for the field trials the system was installed in a small village near Saswad (Pune, India). Two posts were fitted at one corner of the crop field where major problem faced by the local farmers was due to Wild pigs (see Figs. 8 and 9).

Observations were noted from the day of the installation. Table 3 shows the observations taken for the period of 30 days. The crop damage occurred for some days even if the system was installed because there was disturbance in alignment of light source and detector which resulted in intruder entry without any alert signal. In the second case the system was active but there was no animal attack.

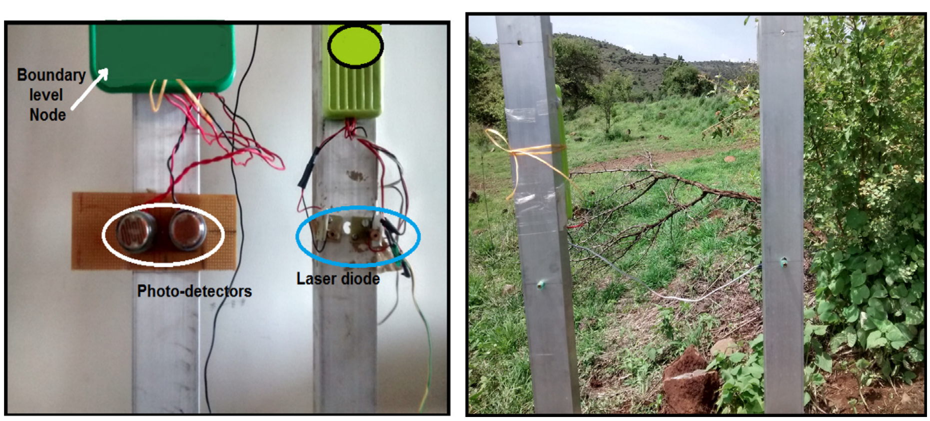

Fig. 8. Installation of the intruder detection system in the test field, Saswad, Pune.

Fig. 9. Set of transmitter, receiver posts and nodes positioned in the test field.

Table 3
Observations recorded by the farmer after the system installation.

Parameter under consideration	Effects observed in the duration of 30 days (%)	Remarks
Crop damage occurred	40	The system was ineffective due to failure in the circuit operation.
No crop damage	42	The system was active but the animals did not cross the boundary and returned.
Effect of perimeter control system observed	20	Animal attack took place and the system gave an alert and the animals were diverted from the boundary.

6. Conclusion

Crop protection against animal attack is an important category of WSN applications with prospective benefits for the farmers and society as a whole. In this paper, we propose a deployment of WSN based crop protection system to divert the animals from the crop field area. The field test for this system is in plan to test its effectiveness. Farmers are the end users of this system and they can tailor the node placements in their field as per the location need.

Such a system can be installed easily and can be cost effective if planned appropriately. The system is developed in order to be easily adaptable by the farmers. While implementing this system in the field the ecological balance is not disturbed as the animals are not hurt and the system do not create any damage to the animals entering the crop field boundary. The power requirement of the nodes is minimized by including the Sleep modes wherever necessary and solar panel based charging is provided with the system. The central base station node can be solar powered. This system will reduce the extra guarding load on the farmers to a major extent and can save their crop. The laboratory level trials of the systems have shown positive results. Field tests carried out with the prototype model at Saswad (Pune, India) worked out to be functional except for few technical faults in the circuit components which is rectified. Currently, focus is to be given on the design of intrusion detection system to enhance its robustness and reliability in the crop field. Additional audio signal patterns and alert mechanisms will be included in this system in order to divert the animals out of the farm area. More field tests would be carried out to validate the system operation. Assistance of state-of-art technology for detecting the animal intrusion and then their diversion from the field in order to protect the crops is achieved with this system design.

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