AID: A Prototype for Agricultural Intrusion Detection Using Wireless Sensor Network

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Abstract—**In many developing countries, agriculture is one of the primary livelihoods of common people. Agriculture requires various types of technologies for improving crop yields. The attack of animals in the agricultural land and the theft of crops by humans cause heavy loss in cultivation. In this work, we propose a hardware prototype using Wireless Sensor Network (WSN) for intruder detection in an agricultural field. The proposed system is named *Agricultural Intrusion Detection* (*AID*). AID helps to generate alarms in the farmer's house and at the same time transmits a text message to the farmer's cell phone when an intruder enters into the field. In order to implement the proposed scheme, we design and deploy Advanced Virtual RISC (AVR) micro-controller-based wireless sensor boards over an outdoor environment and evaluate the performance.**

Index Terms—**Wireless Sensor Networks, Intrusion Detection, AVR Micro-controller based Wireless Sensor Boards.**

I. Introduction

The rapid development of Micro-Electro-Mechanical Systems (MEMS) technology has given rise to the emergence of the Wireless Sensor Network (WSN) technology. In a WSN, sensor nodes sense some physical phenomena, and transmit those sensed data to the sink. WSNs are used in various fields of applications such as agriculture, target tracking, health monitoring, and wildlife tracking [1]–[3]. Due to the resource-constrained nature of WSNs, a sensor node transmits data to the sink through single- or multi-hop connectivity [4]–[7].

Agriculture is the one of most important resources of any developing nation. Currently, WSN technology is widely used for different purposes of agriculture. In an agricultural field, the deployed sensors sense different physical phenomena around them such as temperature, humidity, and water level of the field. Thereafter, the sensed data are transmitted to the sink or any centralized device through single- or multi-hop connectivity. After collecting the data, different decisions are taken by the farmer. Due to theft in agricultural fields, often there is substantial loss is incurred, which prevents efficient productions of crops. In this work, we present a prototype for intrusion detection using WSN in an agricultural field. The designed prototype enables a farmer to receive text messages on his/her cell phone. Further, an alarm is generated if any intruder enters into his/her cultivation field. To implement the designed prototype, we develop AVR micro-controller based wireless sensor boards. Each of the boards contains two types of sensors – (a) Passive Infrared (PIR) and (b) Ultrasonic sensor.

A. Motivation

Agriculture is an important source of income in developing countries. WSNs have found different types of use in agricultural monitoring for several years. Physical phenomena such as temperature, humidity, and rainfall over an agricultural region can be monitored by a WSN. Currently, agricultural theft from fields is a serious concern affecting the efficiency in cultivation in many countries. Few statistics are reported through different sources summarizing the extent of loss from agricultural theft [8]. Therefore, to provide security from intruders to the agricultural field, we design a prototype for intrusion detection inside agricultural fields. This detection system enables the farmer to receive text messages as well as alarms on the entry of an intruder in the agricultural field.

B. Contribution

In this work, we propose an intruder detection system for use in agricultural fields. The specific contributions of this work are summarized as follows:

(i) We design a prototype for intruder detection system, that generates alarms in the farmer's house and triggers the generation and transmission of a text message, when an intruder enters into the field.
(ii) In order to perform experiments with the prototype, we develop AVR micro-controller based wireless sensor boards.
(iii) We provide empirical results of the implemented prototype in a real agricultural field.

The rest of the paper is organized as follows. Section II describes the prior art related to this work. Section III describes the board which is used to design the prototype AID. The design of intrusion detection prototype is described in the Section IV. Section V provides experimental results of the intruder detector, AID. Finally, we conclude our work in Section VI.

II. Related Work

Agriculture is an important resource, particularly in the developing countries. Technological advancements have facilitated agricultural development worldwide. New technologies such as Geographic Information Systems (GIS), Global Positioning Systems (GPS), Wireless Sensor Network (WSN), and Remote Sensing (RS) are widely used for agriculture. WSN plays an important role in agriculture for monitoring different activities in the cultivation field. Wang *et al*. [9] discussed the applicability of WSN in agriculture. According to the authors, WSN is used in precision agriculture for different purposes such as – spatial data collection, precision irrigation, variable-rate technology, and supplying data. Further, they discussed how WSNs can be used for environment and weather monitoring in agriculture. Konstantinos *et al*. [10] reported few advantages of WSNs in agriculture such as its ability to monitor the field for a long time, distance decision making, and GUI-based monitoring system. Pierce *et al*. [11] developed regional and on-firm sensor networks to monitor the air temperature during frost/freeze protection events. The authors considered two types of radios – base radio and roamer radio. The base radios are deployed as a star topology. These deployed base radios collect data from the environment and transmit to the roamer radio. The roamer radios are further connected to the computer, and finally the collected data from the computer are used by the software AgFrostNet. Shu-ming *et al*. [12] developed a prototype to monitor the acoustic emission signal from crop water stressing. For the prototype, MicaZ nodes and MTS310 sensor boards were used. The authors proposed an inter-cluster multi-hop routing. Lilly *et al*. [13] developed a system that monitor the soil properties and fertilization level based on WSN. Using this system, the authors attempted to monitor soil property, amount of fertilizer used, and amount of water level in the area. Gutierrez *et al*. [14] developed an automated irrigation system that automatically optimizes the water in an agricultural field. In this system two types of sensors are placed on the root zone of the plant.

In the exiting literature, different applications of WSN in agriculture are discussed. However, the authors have overlooked the issue of theft in agricultural field due to unauthorized intruders. Here, we consider the entrance of an intruder as an important issue, and designed a prototype of the intrusion detection system.

III. AVR micro-controller based wireless sensor board

To perform experiments with our designed prototype, we developed AVR micro-controller based wireless sensor boards. These boards are configured to work for sensing an event and transmitting the sensed data to the sink, through single- or multi-hop connectivity. The major component of a board are:

1) Micro-controller ATMEGA324PA-PU
2) ZigBee (IEEE802.15.4)
3) Liquid Crystal Display (LCD 16X2)

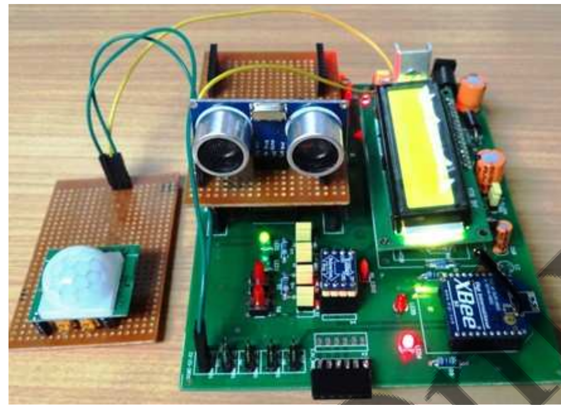


Fig. 1: AVR micro-controller based wireless sensor board

4) Sensor
   a) Passive Infrared (PIR)
   b) Ultrasonic

The sensors of AVR micro-controller-based wireless sensor board sense some physical phenomena from the environment, which are processed by the micro-controller. Further, ZigBee functions as wireless transmitter units of the boards. The LCD is used for displaying different activities of the experiment. Each of the boards has an internal Electrically Erasable Programmable Read-Only Memory (EEPROM) of micro-controller, that helps to store any data temporarily. Thus, these boards function as complete sensor “nodes” serving two folds of purposes – (a) working as a sensing unit for sensing any intruder in the deployed region, and (b) after sensing the intruder’s entrance into the field, inform the farmer. A sensor node is shown in Fig.1

IV. Intruder detection System

In the prototype designed, i.e., AID, the sensor nodes detect and monitor intruders that enter into the agricultural field. After the detection of an intruder into the field, the detected information is transmitted through other intermediate nodes or directly to the sink. The sink further alerts the farmer through text messages in his/her cell phone. Along with the text message, an alarm is generated in the device located inside the farmer’s house. This alarm and the text message indicate the entrance of intruder into farmer’s agricultural field.

The AID architecture has four layers based on their functionalities, as shown in Fig. 2. Layer 1 consists of two types of sensing activities, i.e., sensing by Passive Infrared (PIR) and ultrasonic sensor. When an intruder enters into the field, the PIR sensor senses the intruder, and the node is activated. Thereafter, the ultrasonic sensor measures the distance of the intruder from field boundary. The sensed data from PIR and ultrasonic sensors are processed by the micro-controller present in Layer 2. After the detection of an intruder, the information is transmitted to the sink through single- or multi-hop connectivity, with the help of ZigBee (IEEE802.15.4). Routing of the information from the node to the sink, is the responsibility of Layer 3. Finally, in Layer 4, the GSM

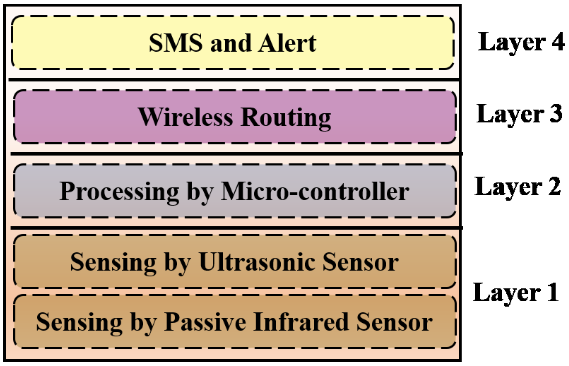


Fig. 2: Layers of AID

technology is used to generate SMS to the farmer's cell phone, and simultaneously, an alarm is generated in the farmer's house. By receiving the SMS and alarm, the farmer gets the information about the entrance of an intruder in the field.

A. Deployment Scenario

We deploy 20 sensor nodes over a square agricultural field with side $36m$. Initially, all the nodes are in the sleep state. The nodes are activated if any intruder enters into the agricultural field. Our interest is to detect intruder that tries to enter into the agricultural field. The intruder may be an animal, human, or a vehicle. All the deployed sensor nodes are connected with one another through wireless link to form a network. Each of the deployed sensor nodes is able to adjust their power four levels. Thus, the communication range of a node can be set up to four steps, by adjusting the power level. The maximum communication range of a sensor node is represented by R.

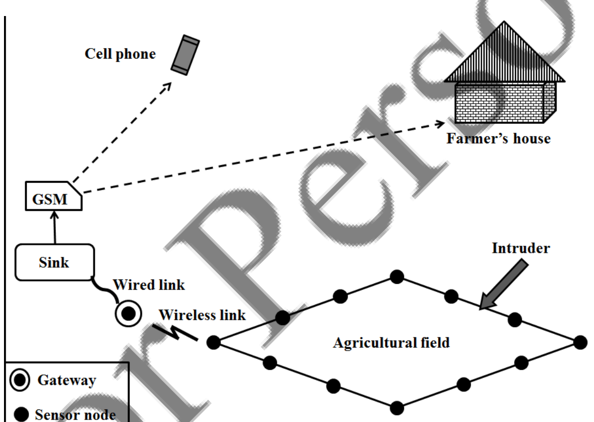


Fig. 3: Description of AID

Each sensor node consists of two types of sensors — (a) Passive Infrared and (b) Ultrasonic. Among these sensors, the PIR sensor senses the movement of human or animal. The ultrasonic sensor determines the distance of the object within the agricultural field. In our application, a sensor node works in two ways (a) it senses the object that enters into the agricultural field (b) works as a router to forward the data towards sink that are received from other nodes. Further, the sink node transmits message to the GSM-enabled alarm device inside the farmer's house to produce the alarm. Simultaneously, the sink sends text messages, based on the data received from deployed sensor nodes in the agricultural field.

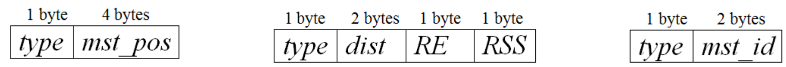
A scenario of deployed hardware prototype is depicted in Fig. 3. In this figure, few sensor nodes are deployed on the boundary of an agricultural field. When an intruder enters into the field, it is detected by one of the deployed nodes. By single- or multi-hop connectivity, the intruder detection information is transmitted to the gateway through wireless link. Further, the gateway transmits the information of intruder detection to the sink. As the GSM module is already connected to the sink, the sink is able to send the information by text message in the cell phone of farmer and generates an alarm in the farmer's house.

B. Intrusion Detection and Auto Alert procedure

WSNs are resource-constrained in nature. Thus, all the deployed sensor nodes initially remain in the sleep mode. The sensors located in the development board (node) detect any intruder that tries to enter into the agricultural field. After detecting, the node sends the information to the sink. A sensor node forwards the information through intermediate nodes between the originator node and the sink. In our system a node that detects the intruder is known as MASTER node. The node that detects the intruder chooses another node among its neighbor nodes, as the next hop, for forwarding the information. To choose the next hop, a MASTER node considers the following parameters:

- Received Signal Strength (RSS) of the node at the next hop
- Residual Energy (RE) of the node at next hop
- Distance (D) between the MASTER node and the node at next hop

After detecting an intruder, a MASTER node creates and broadcasts a request message `REQ`. As all the sensor nodes are deployed in a pre-planned basis, the location of the sensor nodes are known. Thus, in the `REQ` message there is a field for the position of the MASTER node. The MASTER node broadcasts the `REQ` packet. The packet format of `REQ` is shown in Fig. 4(a). In the `REQ` packet, the *type* field indicates the type of the message and *MST_pos* contains the position of the MASTER node. On receiving the `REQ` packet, all the neighbor nodes reply back to the MASTER node with a reply message `REP`. `REP` message contains four fields, namely, *type*, *dist*, *RE*, and *RSS*. The *type* in a `REP` indicates the type of the message, whereas *dist* field contains the value of the distance between the node itself and the MASTER node. *RE* and *RSS* fields in the `REP` packet, contain the *RE* and *RSS* of the node itself, respectively. A `REP` packet is shown in Fig. 4(b). Based on the `REP` message, a MASTER node calculates the selection value $\mathcal{S}$ for each of its neighbor node i. Depending upon the selection value, a neighbor node is selected for forwarding the



(a) Request (b) Reply (c) Detection

Fig. 4: Packet format

information of intrusion detection by the MASTER node. The selection value $\mathcal{S}_i$ of a node i is calculated as:

$$\mathcal{S}_i = \left(\frac{RE_i}{RE_{max}} - \frac{RSS_i}{RSS_{max}} - \frac{D_i}{R} \right) \tag{1}$$

where RE_{max} and RSS_{max} are the initial energy and maximum *RSS* of a node, respectively. The master node sends the detection information to that neighbor node which has the highest selection value. The selected neighbor node forwards the detection information to the sink following the same procedure as the MASTER node. The packet format of the detection message is shown in Fig. 4(c). The node, which does not receive any data from any node or does not detect any object for a certain duration of time t, goes into the to sleep state. A node is activated only if an intruder enters the agricultural field or if any of its neighbor nodes sends some data. For activation of nodes, an external interrupt is used. Our deployment scenario on the agricultural field is shown in Fig. 5. The details about the figure are as follows:
Fig. 5(a): Sensor node on the vegetable field is deployed such that its sensors can detect the intruder.
Fig. 5(b): In a similar manner, the entire perimeter of the vegetable field is covered by the deployed sensor nodes.
Fig. 5(c): LCD on the node indicates when an intruder is detected and the detection message is transmitted to the sink.
Fig. 5(d): The intruder detection information is shown on the screen of the sink.

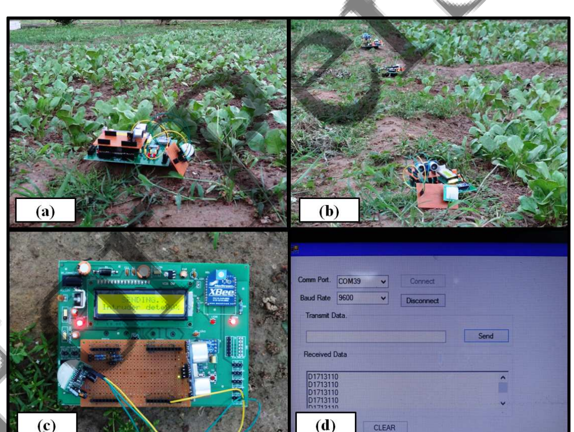


Fig. 5: AID on vegetable field

The detailed flowchart of the AID is shown in Fig. 6

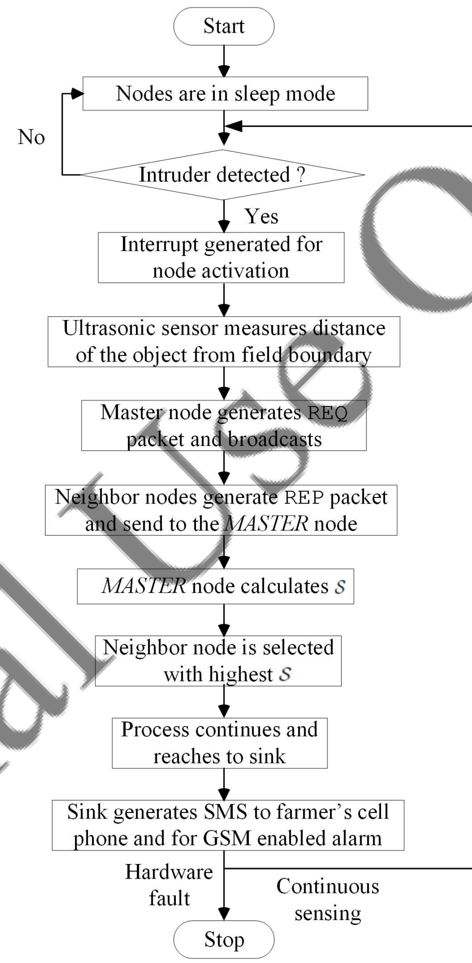


Fig. 6: Flowchart of AID

V. Performance Evaluation of AID

A. Experimental Setup

We deployed 20 sensor nodes over a square-shaped vegetable field. Each side of the field is of 36 m. The sensor nodes are deployed on the perimeter of the field. Each sensor node is connected with others through single or multi-hop connectivity. The details specification of the sensor nodes are shown in Table I.

When an intruder enters into the field through the boundary (perimeter) of the field, the PIR sensor detects the object. Simultaneously, the ultrasonic sensor senses the distance at which the object is located. At this moment the node gets activated. The PIR sensor continuously senses the movement of any object that is located within 6 m from itself. On the other hand, the ultrasonic sensor detects the distance of the

TABLE I: Board Specification

Components	Specification
Micro-controller	ATMEGA 324PA-PU
SRAM	2 KB
EEPROM	1 KB
Flash Memory	32 KB
Power Supply	4.8 V
Clock Frequency	8 MHz
Addressing Mode of ZigBee	16 $bits$
Power Supply of ZigBee	3.3 V
Compiler	MikroC PRO for AVR
Language	Embedded C
Rechargeable Battery	Model No: GP1300 1.2 V
Passive Infrared Sensor	Model No: HC-SR501
Ultrasonic Sensor	Model No: HC-SR04

object that are located within 4.5 m from itself. Finally, an object is detected as intruder, when the PIR sensor detects the object as well as the distance between the ultrasonic sensor and the object is 15 cm. Following the procedure shown in Fig. 6, the detection message is transmitted to the sink node. The number of equipments used for experiment is shown in Table II.

TABLE II: Field Setup

Components	Number
Number of Sensor Nodes	20
Field Side Size	36 m
Number of Gateway	1
Sink	1
GSM-based Alarm Device	1
Cell Phone	1

B. Results

We have experimented on the designed prototype in a vegetable field and collected the data for 3 $hours$. We have experimented the performance of AID based on three parameters, as follows:

- *Accuracy* (A): Accuracy is defined as the number of intruders detected by AID, in percentage, over the total number of intruders who actually enter into the field. Mathematically:

$$A = \frac{N_D}{N_E} \times 100 \quad (2)$$

- *Percentage of average activated nodes* (P): Total percentage of activated nodes require to detect an intruder. Mathematically:

$$P = \frac{n \times 100}{N \times N_D} \quad (3)$$

- *Voltage* (V): Degradation of value of voltage in a certain time duration t to detect total number of intruders in that duration t

where

N : Total number of nodes present in the network
n : Total number of activated nodes
N_D : Total number of detected intruders by AID
N_E : Total number of intruders entered into the field Fig.

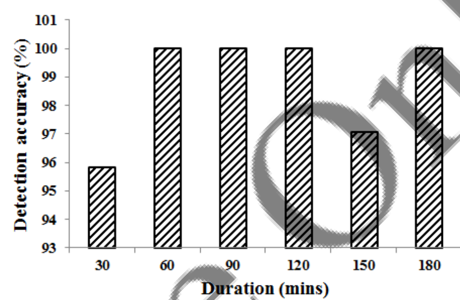


Fig. 7: Detection Accuracy

7 shows how accurately an intruder is detected by AID. In this plot, we consider total 180 minutes along X-axis with an interval of 30 minutes. We have collected the data for accuracy after every 30 minutes. In each of the case, we observe that accuracy is always above 95%.

Fig. 8 depicts the plot for percentage of average activated nodes with our experimental time (180 minutes). In this plot, the experimental time duration is shown along the X-axis in steps of 30 minutes. In this plot, we observe that the percentage of average activated nodes is below 14%. The trend of the plot sometimes increases and sometimes decreases. The possible reason for this type of pattern is – the dynamic routing procedure used for delivery of a detection packet to the sink as shown in Equation (1). Therefore, the proposed routing procedure sometimes selects more number of intermediate nodes to deliver the detection packet to the sinks and sometime selects less.

The average activated sensor nodes is calculated by the total number of sensor nodes activated to transmit the total number of detected packets to the sink in a certain duration of time. In the first 30 minutes of experiment, AID detects 23 times of intruders entering into the field.

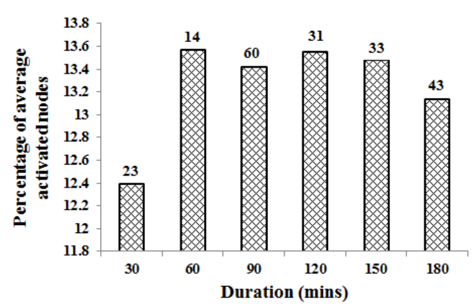


Fig. 8: Average Activated Nodes

The degradation in average voltage with different time instants is depicted in Fig. 9. The initial value of average voltage is 5.10 Volt. We observe in the plot that, with increasing time duration, there is gradual degradation in the trend of the plot.

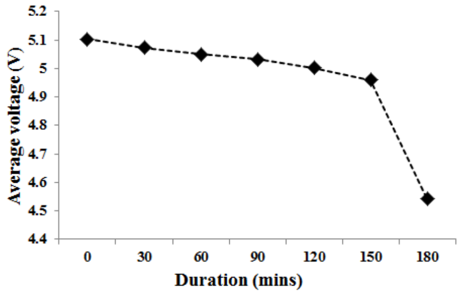


Fig. 9: Average Voltage Degradation

VI. Conclusion

In this work, we have designed a prototype for intruder detection using WSN. For the hardware prototype, we have developed AVR micro-controller based wireless sensor board. The board is equipped with two types of sensors – PIR and ultrasonic. When an intruder enters into the agricultural field, the sensor board detects the intruder, and transmits a detection message to the sink. For transmitting the detection message, each of the node chooses one of its neighbor node as next hop, considering Received Signal Strength and Residual Energy of the neighbor node. This prototype ensures the farmer about the detection of intruder in his field by sending SMS or generating alarm. Thus, here we have provided a low-cost and energy efficient complete solution for intruder detection.

In the future, we plan to develop the intrusion detection system for agricultural field using learning automata. By doing so, the system can learn by itself, in order to detect intrusion in the agricultural field in an energy efficient manner. We envision to develop an agricultural monitoring system that monitors the conditions of the crops and provides the security from theft.

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