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A Smart dust network system for monitoring Enemy's Intrusion using Camera-Acoustic-Magnetic-Thermal- Vibration Signatures

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Abstract

The greatest threat to national security is "Terrorism" infiltrating through borders. In critical border areas such as Kashmir and Bangladesh regular forces or even satellites cannot monitor these intruding terrorists as the area monitored is quite large and quite complex. This project provides an innovative and effective solution to this problem.

The project aim is to design a next generation intelligent ultra small dust like wireless sensor motes which has multiple onboard sensors, camera and a processor, which has the ability to detect an enemy intrusion across borders and battlefields. Thousands of these smart dust motes can be deployed within a large area in a few hours by one or two men. The motes can form a network on its own among them, are small in size, rapidly deployable, have wireless connection to outside world. They detect the intrusion and classify it into vehicles or individuals and groups. Onboard hardware include a variety of sensors for vibration/seismic, magnetic, acoustic, thermal signature recognition and camera, a microcontroller for processing these sensor values and a ZigBee transceiver for communication over a wireless network. The system process the sensor readings, classify the targets and the tracking history can be viewed in the Graphics LCD display attached in the central monitoring unit. The central monitoring node acts as the parent node in a peer to peer wireless network model. The dust motes communicate with central parent node using wireless ZigBee network

Keywords: *MEMS accelerometer, Inter Integrated Circuit (I2C), Cortex microcontroller software interface standard (CMSIS), Advanced RISC Machine (ARM), Serial Peripheral Interface (SPI),Smartdust mote.*

INTRODUCTION

Intrusion detection is a major problem in this application. Timely detection of intrusion is the very sensitive part in detecting the intrusion. When intrusion happens in large terrain or rough areas it is hard to detect, since surveying those areas through men becomes a difficult task. Intrusion detection in the given application normally deals with the detection of objects and classifies it in to human or vehicle or groups and track the enemy intrusion. Enemy intrusion is identified, classified and tracked by using the next generation intelligent ultra-small dust like wireless sensor motes which has multiple onboard sensors and a controller, which has the ability to detect an enemy intrusion across borders and battlefields. These smart dust motes are the collection of sensors and a controller. Thousands of these smart dust motes can be deployed across the border in a few hours by one or two men. These motes are small in size as shown in Fig 1, are rapidly deployable and they form a network on its own and give the result to the outside world through wireless connection. Onboard hardware consists of variety of sensors such as vibration/seismic, magnetic, acoustic and thermal signature recognition, and microcontroller for processing these sensor values and a radio transceiver for communication over a wireless network. The mote consists of all this hardware is called the dust mote. The parent mote (controlling node) consists of a controller and a graphics display through which the tracking history can be viewed..

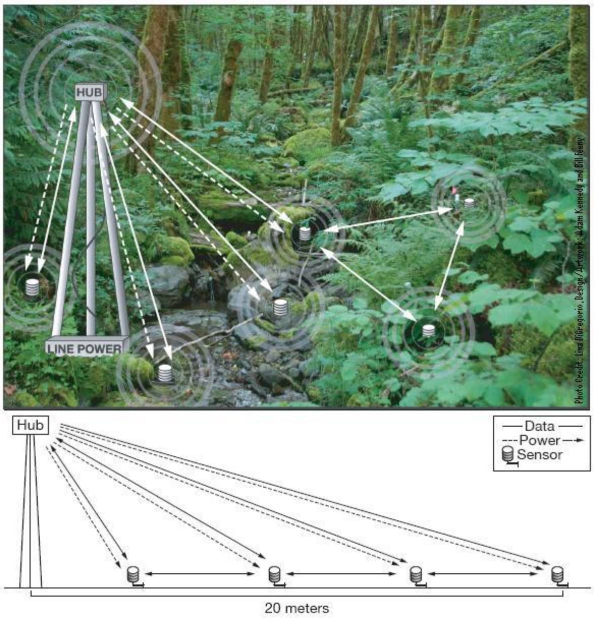

Figure 1: Smartdust deployed in a forest

DISCUSSION

The aim of this paper is to implement a border intrusion detection system using small and cheap sensor nodes which can be left unattended and are difficult to detect because of their size. We are not using large expensive equipment for monitoring which can cover a larger area for monitoring because if this equipment is disabled, intentionally or unintentionally, it will result in dataun availability. One of the main drawbacks pointed out in sensor networks is battery power. The need to frequently change batteries and the corresponding manpower required for this task is a big deterrent to the usage of sensor networks. Recent advances in the field of powering sensor nodes suggest the idea of using a mobile-host based wireless energy transmission system to provide power. The mobile host has the capability of wirelessly transmitting energy to sensor nodes on an as-needed basis. The wirelessly transmitted microwave energy is captured by a receiving antenna, transformed into DC power by a rectifying circuit, and stored in a storage medium to provide the required energy to the sensor node. Also, energy for the sensor nodes can be scavenged. Some long-lasting sources of sensor power are: solar power, temperature gradient, vibrations and pressure variations. The above mentioned methods will be extremely helpful in solving the critical issue of power in the wireless sensors domain. Using sensor networks for border monitoring has a plus point that the entire border area does not have to be necessarily covered. The terrain can be helpful in reducing cost since some areas will be inaccessible and hence sensor nodes need not be spread in these areas. Even though building fences along the entire border is an option, there are several difficulties associated with it. For example, after building a fence it is necessary to ensure that the fence is not broken at any place. Using electric fences would be an enormous overhead. Moreover, if a fence is constructed, it will have to be constructed through and through. Sensor networks have an advantage here as terrain can be assistive and nodes need not be placed everywhere. Another concern while considering the use of sensor nodes is how the nodes will be placed. If sensors are air dropped then the number of sensors required will be much higher. This issue can be addressed by deploying the sensors in a few hours by one or two men. In the terrain which is accessible, the nodes can be placed manually by travelling short distances in a helicopter (if roads are nonexistent). If the terrain is difficult to access, then air dropping is an option or more advanced techniques like using laser guns to shoot and place the sensors in the ground may also be used.

Related Work on border surveillance

There are several works carried out in the area of border surveillance. As an example, the study conducted by T.J. Nohara explains the use of commercial approach to the deployment of radar surveillance [3]. The literature says, “surveillance solutions must be multi-mission suitable, scalable, flexible, maintainable, upgradeable, interoperable, shareable, and affordable”, which is very true when it comes to border surveillance and other security systems. Smartdust system satisfies the above mentioned features and its compact size is an added advantage when deployed in the battlefields. To give another example, the work done by C. Neumann and his colleagues explains about the protection of our borderlines as well as military camps using Radar surveillance methods [4]. The challenges of remote border monitoring have been detailed in the work conducted by P.Pratap and his colleagues [5]. The paper discusses three major issues to be addressed to build an effective ground surveillance system and the issues are „providing reliable and efficient power‟, „providing adequate and timely maintenance to minimize downtime‟ and „networking systems for effective data transmission‟. Concluding, the work says that a system that overcomes these challenges will provide a “cost-effective solution requiring minimal support infrastructure solution to meet border monitoring and protection needs.” Smartdust system ensures that it meets these challenges, to be discussed in the following sections. Numerous other works were carried out in designing border surveillance systems and also improving on the existing methodologies. Most of the works carried out was about improving on the existing Radar technologies, using unmanned air vehicles and fiber optic sensing [3][4][6][7].This paper proposes a system based on smartdusts for border surveillance applications that can help solve many of the challenges posed by conventional systems especially concerned to power consumption, maintainability, safety and coverage. The system structure of the smartdust networks is presented in the next section followed by the hardware and software design in the third and fourth sections. The third section also details about the components used and it‟s set up. The software design section also includes a high level flow chart for the system and the forthcoming section describe the output obtained when the system was put under test. The final section describes the features, few concerns and some enhancements of the proposed project.

SYSTEM STRUCTURE

The project aims to develop a system of two motes that communicates with a central monitoring mote. The system structure can be broadly classified into two- smatdust mote circuit and the central monitoring mote circuit. The block diagram for the smartdust network is shown in Fig. 2. The system consists of the following components/modules:

a) Microcontroller: 32-bit ARM Cortex-M3 microcontroller, to control the smartdust mote.

b) Display: Graphics LCD, to show the intrusion type and tracking history.

c) Communication: IEEE 802.15.4 wireless protocol, for communication between motes.

d) Thermal sensor: Enhanced PIR sensor, to sense the acoustic sound signals.

e) Vibration sensor: 3-axis MEMS accelerometer, to sense the acoustic sound signals.

f) Acoustic sensor: MEMS Microphone is used to sense the acoustic sound signals.

g) Magnetic sensor: Intruders carrying weapons and moving in vehicles can be identified using their magnetic signature in this AMR Magnetic sensor.

h)Digital Camera: A high speed video camera with VGA output and SCCB control.

i) Memory Card: hold the photos taken by the camera and other scan result details.

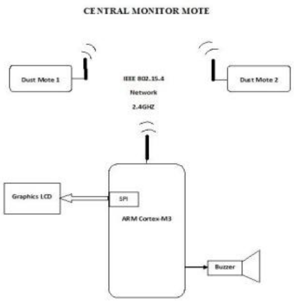

Figure 2: Block diagram of smartdust network.

Each smartdust mote consists of a variety of sensors like magnetic, thermal, and acoustic and vibration sensors for detecting the respective signatures. The controller present in the dust mote processes these values and sends them over the wireless network using IEEE802.15.4 protocol. The structure designed for a smartdust mote is shown in Fig. 3.

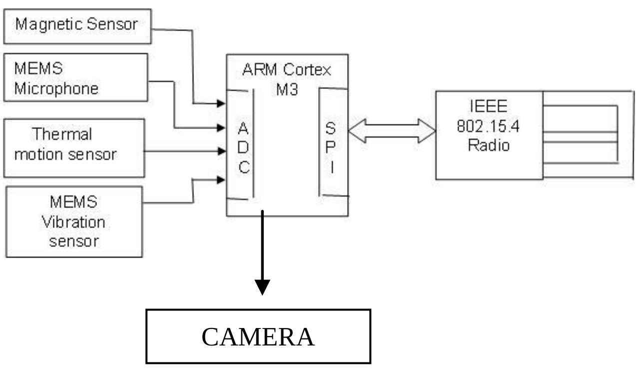

Figure 3: Proposed block diagram of smartdust mote.

HARDWARE DESIGN

The major hardware used in the project are ARM controller, sensors, transceiver, graphics display, buzzer, crystal and power supply. The project intends to develop two smartdust mote boards and one central monitoring mote. A list of the components used for the project work can be found in Table 1.

Table 1: List of components

Component	Specification	Number
ARM controller	ARM LPC1313	3
PIR sensor	SB0081	2
Vibration sensor	PHIDGETS 1104	2
IEEE802.15.4 radio transceiver	MRF24J40	3
Magnetic sensor	KMA199E	2
Graphics display	NOKIA 5110	1
MEMS microphone	SPM0404HE5H	2
Crystal	12 MHz	3
Camera sensor	VGA	1
Buzzer	-	1

Other componenets used are LEDs and switches as per need.

The circuit diagram for the central monitoring mote and smartdust mote are shown in Fig. 4 and Fig.5 respectively.

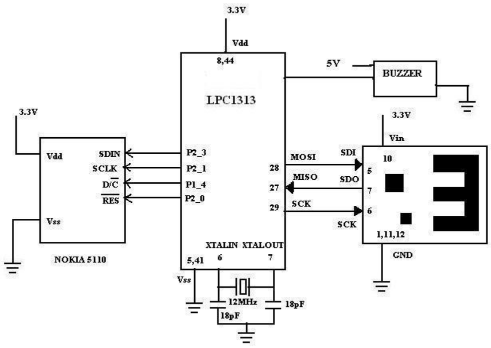

Figure 4: Circuit diagram of central monitoring mote

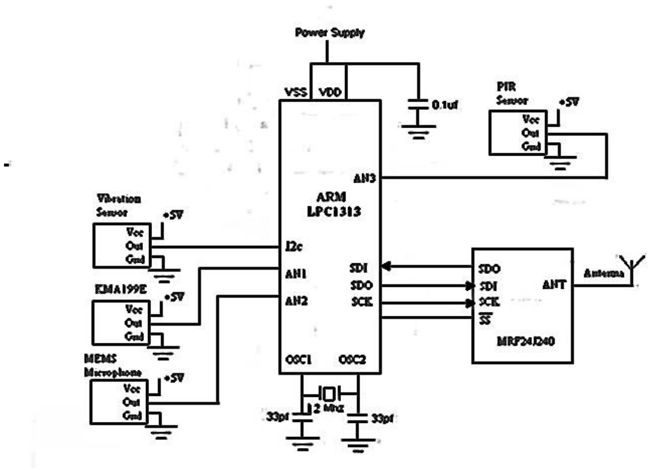

Figure 5: Circuit diagram of smartdust mote

Each of the key components used in this work are detailed here.

i. *ARM Controller* - The project uses ARM Cortex M3 controller, which is the next generation 32 bit ARM processor for embedded applications based on ARMv7-M architecture. The specialty of this ARM controller is its Harvard architecture [8][9]. The separate instruction and data buses allow parallel instruction fetching and data storage.The ARM Cortex - M3 controller has been chosen in this work for the following reasons: better energy efficiency, more functionality out of battery life and ability to meet increasing energy demands for low energy products when compared to other controllers [8].It also has the smallest code size for any microcontroller. Reducing the code size is the key to squeezing your application code into minimum amount of flash [8].

ii. *Magnetic sensor* - The magnetic sensor used is KMA199E which is a magnetic angle sensor system (numbered 3 in Fig.6). The Magneto Resistive (MR) sensor bridges and the mixed signal Integrated Circuit (IC) are integrated into a single package. This angular measurement system KMA199E is pre-programmed, pre-calibrated and therefore, ready to use. The KMA199E allows user specific adjustments of angular range, zero angle and clamping voltages [10]. The settings are stored permanently in an Electrically Erasable Programmable Read-Only Memory (EEPROM).

iii. *MEMS Microphone* - MEMS microphone is similar to the standard ECMs (Electro condenser microphones) found in modern consumer electronics, except that the components are built onto a single chip using CMOS technology, rather than assembled from discrete parts. It can sense the acoustic signals [11]. The MEMS microphone used is SPM0404HE5H(numbered 2 in Fig.6).

iv. *PIR Motion sensor* - The motion detector module used is SB0081, which is a pyroelectric sensor module developed for human body detection (numbered 1 in Fig.6). A PIR detector combined with a Fresnel lens are mounted on a compact size PCB together with an analog IC, SB0081, and limited components to form the module [12]. It has a very compact size and operates at 3.3V.

v. *Vibration sensor* - It is a piezoelectric transducer, which when displaced from the mechanical neutral axis; the bending creates strain within the piezoelectric element and generates voltage (numbered 4 in Fig.6). We have used PHIDGETS 1104 type in the project. The type of measurement used by the device is ratiometric [13].

vi. *Transceiver* - The MRF24J40 is an IEEE 802.15.4™ Standard compliant 2.4 GHz RF transceiver [14]. The MRF24J40 creates a low-cost, low-power, low data rate (250 or 625 kbps) Wireless Personal Area Network (WPAN) device (numbered 5 in Fig.6). The MRF24J40 interfaces many popular microcontrollers via a 4-wire serial SPI interface, interrupt, wake and Reset pins.The MRF24J40 provides hardware support for energy detection, Carrier Sense, CSMA-CA Algorithm, Automatic Packet Retransmission, Automatic Acknowledgment. The Wireless Personal Area Network (WPAN) focuses on low-cost, low-speed ubiquitous communication between devices. The range of operation is 10-100 meter and provides a transfer rate of 250 Kbit/s. It uses CSMA/CA for collision avoidance. It supports secure communications and employs peer -to-peer or star topology. The operating frequency band is 2400-2483.5 MHz with up to sixteen channels. It uses Offset Quadrature Phase Shift Keying (OQPSK) modulation.

vii. *Graphics LCD* -The Graphics LCD used is Nokia 5110, which is a basic LCD screen for lots of applications. It is mounted on an easy to solder PCB [15]. It uses the PCD8544 controller which is a low power CMOS LCD controller/driver designed to drive a graphics display of 48 rows and 84 columns. This is interfaced to the ARM microcontroller through serial bus interface. The logic supply voltage range VDD to VSS is 2.7 to 3.3 V.

The system has been assembled in three boards, one each for the two sensor motes and one for the monitoring mote. The experimental set up of the proposed system is shown in Fig. 6 and Fig.7.

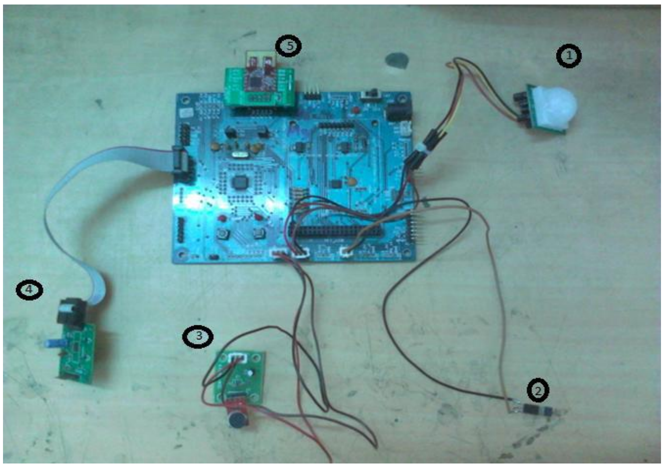

Figure 6: Smartdust mote with sensors

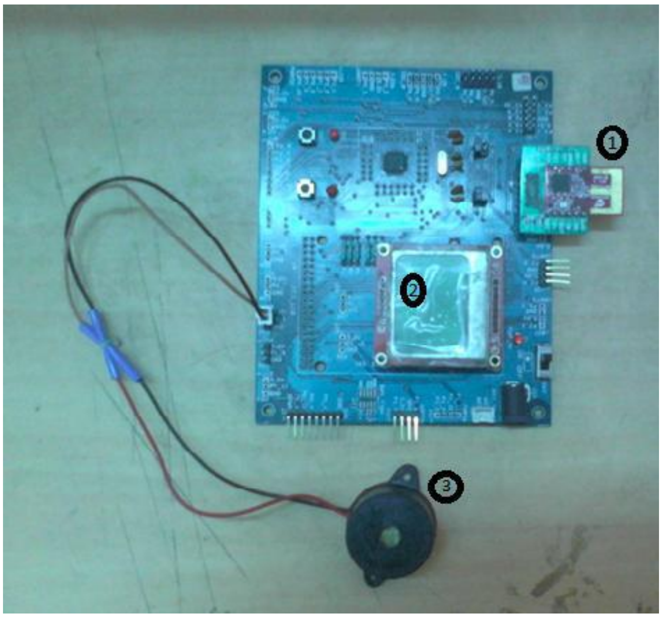

Figure 7: Smartdust monitoring mote

The MEMS microphone is connected to port AD0, metal sensor to AD2, PIR sensor to AD3, MEMS accelerometer (vibration sensor) to I2C port and transceiver through SPI.

SOFTWARE DESIGN

This section details about the software aspects of the project. The development environment used is LPCXpresso IDE, which is a suitable development tool for the LPC1000 series of ARM Cortex-M micro controllers. It is a complete tool chain for LPC1000 series of Cortex-M micro controllers. The different software's used in the project work are CMSIS (Cortex microcontroller software interface standard) from ARM, IEEE 802.15.4 protocol stack, I2C and SPI protocol drivers. The application code programming is done in embedded C.CMSIS is a vendor independent hardware abstraction layer for the Cortex-M processor series. It enables consistent and simple software interfaces to the processor and the peripherals thus; simplifying software reuse. Creation of software is a major cost factor in the embedded industry. Standardizing the software interfaces across all Cortex-M silicon vendor products, would lead to significant cost reduction when creating new projects or migrating existing software to a new device. IEEE 802.15.4 protocol stackis the standard that specifies the physical layer and media access control for low-rate wireless personal area networks. It provides low cost, low speed communication between devices. Here, the emphasis is on low cost communication of nearby devices with little or no underlying infrastructure. I2C protocol driver is a two- wire interface standard. It is used to attach low-speed peripherals to the controller. It uses Serial Data Line (SDA), Serial Clock (SCL). The bus speed is 100 Kbit/s.SPI protocol driver is a serial peripheral interface and is widely used with embedded systems because it is simple and efficient interface. It has three signal wires that hold a clock (SCK), a "Master Out Slave In" (MOSI) data line, and a "Master In Slave Out". A high level process flow chart for the project is given in Fig.8 and Fig.9.

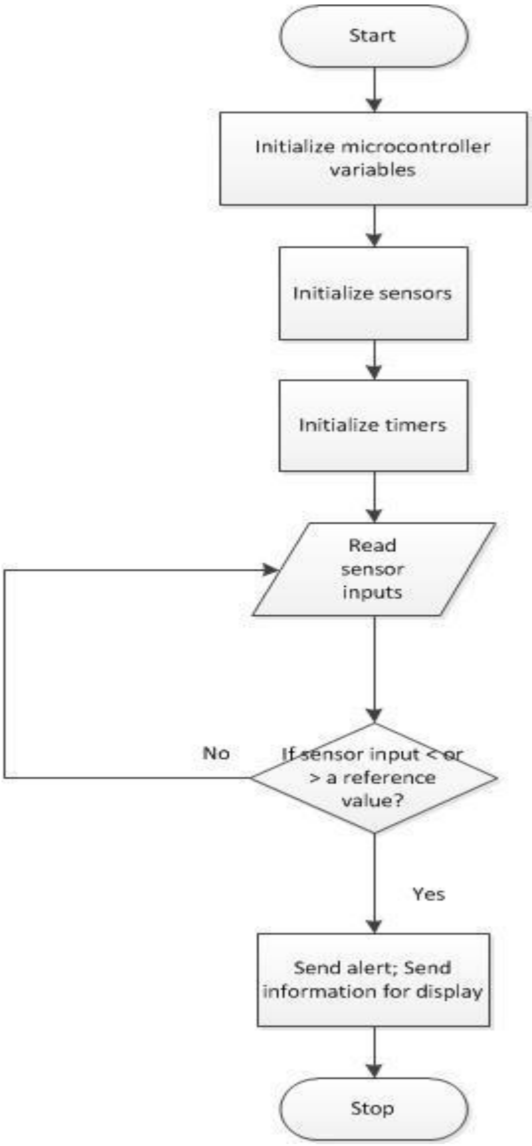

Fig 8: Flow chart for sensor motes

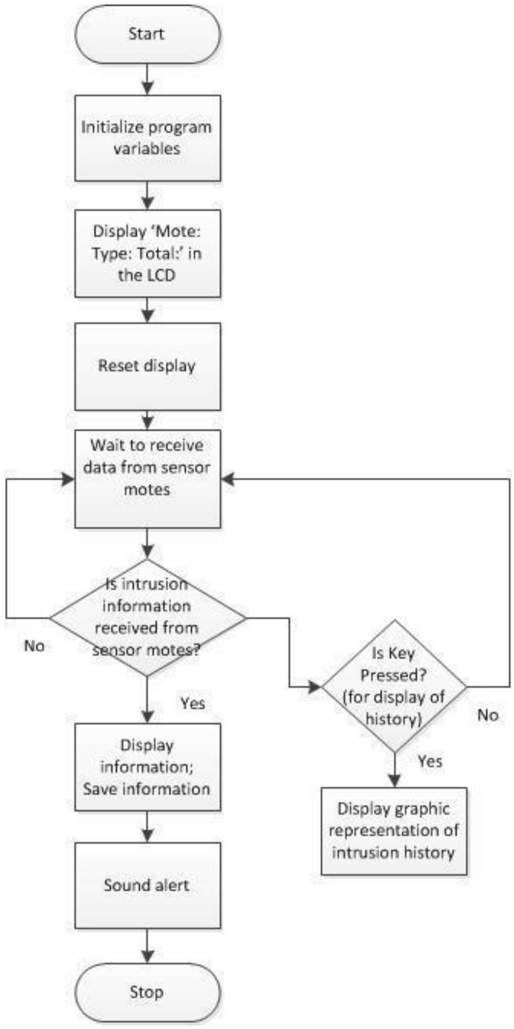

Figure 9: Flow chart for the monitoring mote

RESULT

The sensor motes were placed at a distance of 10 meters (test distance) apart and the monitoring mote placed in its vicinity. On powering each of these boards using the on-board battery, the test LED in the boards were switched ON indicating that wireless connection has been established between them. On giving the inputs, (i)Presence of human, (ii) Human motion, (iii) Human speech and (iv) Movement of a metallic bar, near the sensors, it was found to be detected by the sensors and communicated over to the monitoring mote which displayed which mote detected what (type of input) in the graphics display. It also displayed the total number of inputs it has sensed just to give an idea about the concentration or the strength of intrusion in that area. The output obtained is shown in Fig.10 and Fig.11. The display in Fig.10 shows that the detection of intrusion has happened near mote „1‟ and the type of input has been „human motion‟. It also shows a total of 6 which indicates that it is the sixth time an intrusion were detected in its vicinity. Similarly, Fig.11 shows that mote 1 has detected presence of metal near its vicinity and it was the ninth time it has detected an intrusion.

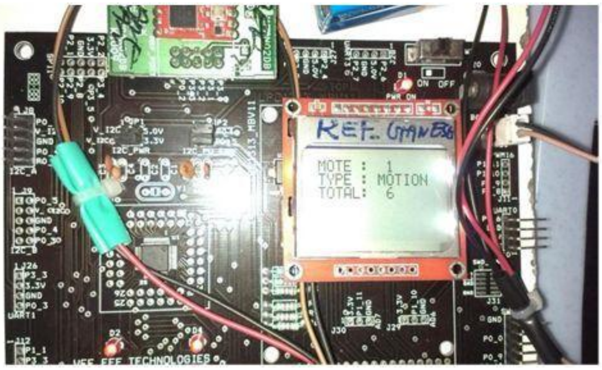

Figure 10: Monitoring mote displaying intrusion, Sample 1.

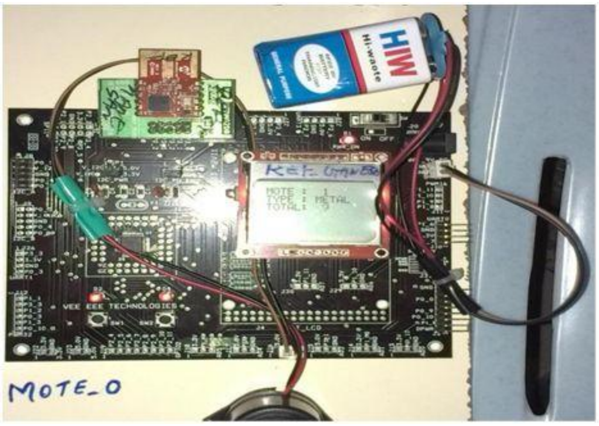

Figure 11: Monitoring mote displaying intrusion, Sample 2.

The system also displays a graph, Fig.12 that indicates the intrusion history by showing which mote has displayed the intrusion on the press of a switch. It approximately gives an idea as to where or near which mote the intrusion is maximum.

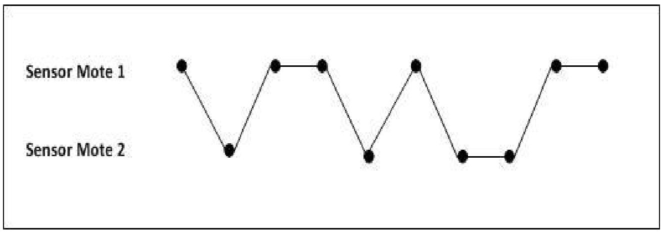

Figure 12: Graph showing in

SYSTEM FEATURES

Relying on the concept of using smartdust networks in border surveillance, thousands of motes may be deployed in any terrain conditions, even inside a dense forest where satellite monitoring is impossible. The smartdusts does not require any maintenance as once deployed they can run for many years. They are not easily prone to enemy detection compared to their conventional counterparts. Variety of onboard sensors makes the mote to identify any kind of intrusion, humans, machines or vehicles. The intrusion path can be tracked using wireless communication between motes. Low power 32-bit ARM Cortex-M3 microcontroller enables the mote to be operated for years from battery power. A portable monitoring node with graphics LCD is used for easy UI where the intrusion path will be plotted graphically and alarm is raised.

CONCLUSION

The proposed system of smartdusts for border surveillance applications was designed, developed and tested in the laboratory. Few suggestions for the betterment of the project would be to make a distinction between animals or humans that is intruding based on the comparison of temperatures. PIR sensor can make out the difference in the body temperatures or the heat from animal and human bodies. Another major point of apprehension would be the availability of the smartdust chips. Smartdust motes are not yet available on a large scale and even if they do most of the motes are of the size of a deck of cards. We could hope for the future motes to be of dust size at the same time available at a reasonable rate.The key downsides of using smartdust networks in border surveillance is the pollution it causes because once deployed the smartdust mote remain in the soil for years. Therefore, let us hope for greener smartdust mote circuits to be developed on a large scale. Also, solar powered batteries can be of great benefit to the smartdust circuits as the circuits once deployed must remain in soil for years without maintenance. Another area of enhancement that we could suggest is that the smartdust motes could be made to give details such as the position of the intrusion and the weather conditions at the place of intrusion.

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