Who Goes There? A PIR-Sensor-Based Intrusion Classification System for an Outdoor Environment

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***Abstract*—This demonstration shows the working of the Passive Infra-Red (PIR) sensor-based Sensor Tower Platform (STP) designed to classify between human intrusion and animal intrusion while rejecting clutter arising from wind-blown vegetation in an outdoor environment. The aim of the research was to explore the potential use of PIR sensor-based Wireless Sensor Network (WSN) as an early-warning system to help mitigate human-wildlife conflicts occurring at the edge of a forest. There are three important features to demonstrate: (a) the STP which employs multiple PIR sensors arranged in the form of a two-dimensional array to give it a key spatial resolution capability that aids in classification, (b) online demo of the deployment of PIR sensor-based WSN at Indian Institute of Science (IISc) by remotely accessing the web-based Graphical User Interface (GUI) of the system, (c) an animation-based simulation tool for PIR sensor to simulate signals corresponding to human and animal intrusions. Deployment setup at IISc offers the detection and classification between human and animals by using the STP, communication of classification decision using IEEE 802.15.4 protocol, short video-clip recording after trigger by PIR sensor decision, and a GUI to monitor the network and fetch the event logs.**

I. Introduction

A PIR sensor-based WSN was developed by our group to help mitigate human-wildlife conflicts occurring at the edge of a forest [1]. This can potentially serve as an early-warning system which can aid forest officials to manage these conflicts. The PIR sensor was the preferred sensing modality due to its passive nature, relatively low cost, wide commercial availability and the ability to operate in the absence of visible light. At the heart of the WSN is a PIR sensor-based STP (see Fig. 1) along with a supervised machine learning based classification algorithm which enables discrimination between signals generated by human, animal and wind-blown vegetation motion (signals generated by vegetative motion are termed as clutter) [1]. Only a small subclass of animals are considered here, those comparable in size and shape to a dog or a tiger.

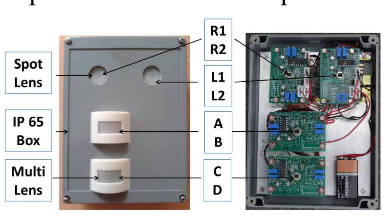

Fig. 1. An outside and inside views of the STP developed by us.

The STP design consists of an arrangement of inexpensive lenses and sensors in the form of an array that gives it a spatial resolution capability that can be exploited to classify intrusions while rejecting false alarms arising from clutter. Similar approaches to STP design have been investigated previously. For example, in [2], the authors arrange PIR sensors at different heights along a pole to improve detection accuracy of humans. However, an important consideration for us was to restrict the size of the developed STP. Closer placement of the sensors could effect the spatial resolution capability. We resorted to a simple but effective trick of off-setting the sensors with respect to optical axis of their associated lenses. This provision offers the required spatial resolution while ensuring a smaller platform size [1].

In addition to the novel STP design, a 3D animation based simulation tool was developed that helped in quickly evaluating competing STP designs without the need for physically collecting data. This helped both for speeding-up the development process as well as for developing an intuition for the kind of signals that can be generated by the PIR sensor in response to various events.

In the later sections, we describe the hardware and software modules of the PIR sensor-based WSN, requirements for demonstration and demonstrated system components.

II. WSN system architecture and Deployment Scenario

One of the features of the demonstration is the online demo of the deployment of PIR sensor-based WSN at IISc by remotely accessing the web-based GUI of the system. Interconnection diagram and snapshots of the components of the deployment carried out at the Main Guest House (MGH), IISc to test the efficacy of the STP and WSN are illustrated in Figs. 2 and 3, respectively (more details can be found in [3]).

Details pertaining to hardware and software modules of the deployment are described below.

A. Hardware Modules

1) *Sensor tower platform:* It has 4 PIR sensor packages along with the associated lenses (see Fig. 1), a Wismote and a Banana-Pi. Each sensor package provides two analog signals which results in total of 8 PIR signals from the STP [1]. The 8 analog signals are read through the Analog to Digital

Converter (ADC) on the Wismote. The Wismote comprises of a low power msp430 micro-controller and a cc2520 radio. The signals are stored on a Banana-Pi which is interfaced with the Wismote via a USB cable. In addition, the Banana-Pi is connected to an intranet for easy access of data.

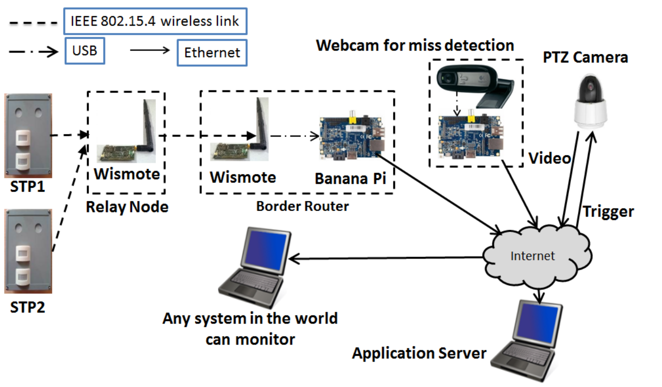

Fig. 2. Components of the deployment system including STPs, the web and Pan-Tilt-Zoom (PTZ) cameras, the server and a laptop of an end-user are interconnected through a network using both wireless and wired links.

2) *Relay nodes and border router:* A Wismote with a 5 dBm antenna is used as a relay node. The WSN is bridged to the LAN using a border router. The border router comprises of a Wismote interfaced with a Banana-Pi module.

3) *Cameras:* A webcam integrated with a Banana-Pi and a PTZ camera are installed at the deployment site to capture the videos to generate statistics concerning missed detections and misclassification, respectively.

4) *Server:* A laptop, connected to the LAN, running the web-server code is placed at the MGH, IISc.

B. Software Modules

1) *Classification algorithm running on the STP:* A low complexity classification algorithm based on energy and correlation features is implemented on a Wismote running Contiki Operating System (OS) as described in [3]. A two-step classification process is adopted. In the first step, the algorithm classifies between intruder and clutter. The detected intrusions are further classified as being either a human or an animal.

2) *Wireless Communication:* The STP, relay nodes and border router communicate using IPv6 over a Low-power Personal Area Network (6LoWPAN) that runs on top of IEEE 802.15.4. There may be packet drops on account of the nature of the wireless medium. Multiple copies of the same decision are transmitted to the border router to combat packet loss. For each classification decision, three packets are sent from the STP to the border router. To ensure that packet drops do not pass undetected, each packet carries as part of its data, a sequence number for the decision. Missing sequence number for a decision on the GUI represents that all three packets corresponding to that decision got dropped.

3) *Time Synchronization for continuous video recording:* The webcam should be time synchronized with the server to detect if any intrusions are missed by the STP. To determine the number of missed detections, the continuous video recorded by the webcam is viewed and the time corresponding to each intrusion is first noted down. These intrusions are verified against the log maintained by the server. Any intrusion that has been missed by the PIR system will not have a corresponding entry in the log. Verifying missed detection in this manner would not be possible if the webcam and server are not time-synchronized. The time synchronization is achieved by using a simple UDP client-server utility.

4) *A PIR-sensor ANimation-based simulAtion (PIRANA):* Supervised machine learning classifiers require training data. Collecting data corresponding to animal intrusions is time-consuming. PIRANA[1] tool is developed that simulates signals corresponding to human and animal intrusion and some limited models of vegetative clutter [1]. Animated 3D models are developed using a software called Blender. The simulation tool was useful both for evaluating various competing designs as well as for developing an intuition for the kind of signals the STP would generate without the need for time-consuming animal motion data collection. Initial testing of the algorithm, which was later implemented on the mote, was performed on the simulated signals.

C. Deployed System Operation

The deployment setup consists of 2 STPs, relay nodes, border router, PTZ camera, webcam and web-server (see Fig. 3). A classification decision from the STP is communicated to the border router in a multi-hop network. The border router forwards the decision to the server upon which server triggers the PTZ camera to record a 10-second-long video for ground-truth verification.

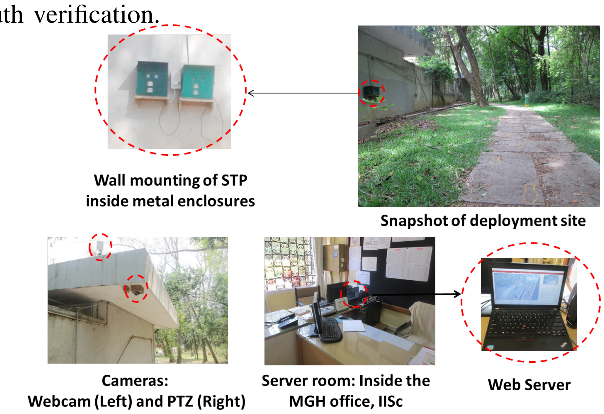

Fig. 3. Snapshots of the WSN deployment at the Main Guest House of IISc.

III. Demonstration Requirement

The following are the requirements for demonstration setup.

- An Internet connection
- A table, at least of 2m x 1m size and a poster board
- 230V three-pin power outlets (at least three)
- Two large displays with VGA cables
- Open area of 5m x 5m would be preferred in front of the table so that the audience can walk in front of the STP
- The set-up time of less than one hour

[1]The simulation tool was previously called ASPIRE.

IV. Features of the Demonstration

The scope of this demonstration is intended to address two sets of questions. First, how do PIR sensors work? and how can the sensor be used to classify between human, animal and clutter? What kind of signal is generated by the PIR sensor? Second, how does the STP developed by us overcome the challenges faced in a real, outdoor deployment? To answer the above questions, the following facets of our system will be demonstrated.

1) *Real-time data collection and visualization:* Conference participants will be able to walk in front of the STP as shown in Fig. 4 and observe the corresponding signals to get better understanding about the signals generated by PIR sensors. For example, variation in signal strengths with respect to distance and speed is shown in Fig. 4.

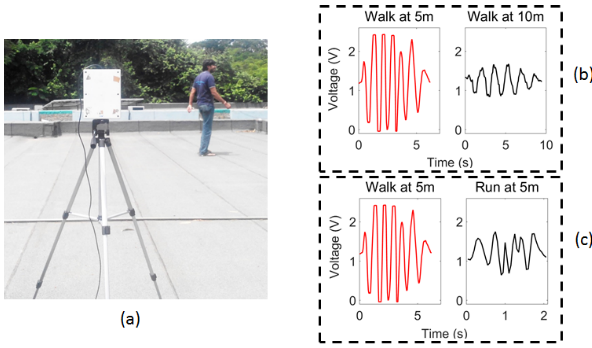

Fig. 4. (a) Illustrating the setup to check the signals for the STP. The STP is placed on a tripod. Walks are done at different distances to observe the corresponding signals, (b) Illustrating the variation in the signal strength for a human walk with variation in distance. The signal strength decreases as the distance increases (considering the flat frequency response for the range of frequencies of interest), and (c) Illustrating the variation in the signal strength for walk and run by human at 5m. The signal strength decreases for run due to attenuation introduced by the frequency response.

The STP design involves the arrangement of an array of 8 sensors along with associated lenses (see Fig. 1). Placement of sensors in the form of an array gives the spatial resolution capability to the STP for the classification tasks. The Field Of View (FOV) of the STP consists of a set of invisible beams (also called virtual beams) along which radiation is received. The intersection of the FOV with a given plane is termed as the Virtual Pixel Array (VPA) [1]. The sensors L_1, L_2, R_1, R_2 help in distinguishing between intrusion and wind-blown vegetative motion based on the type of motion (translational vs oscillatory) while the sensors A, B, C, D help in distinguishing between human and animal motion based on the difference in height as shown in Fig. 6. Better platform design that results in a VPA which can provide easy to differentiate signals for different classes is the highlight of the research done.

2) *Signal retrieval from database:* A Matlab GUI is developed which provides easy retrieval and visualization of stored signals. It helps in quickly comparing the various signals. Conference attendees will be able to visualize the signals for previously recorded human and animal movements. The signals corresponding to human walk at 5m is shown in Fig. 5.

3) *Real-time classification decision:* The classification algorithm is implemented on the Wismote and classification based on the mote-implemented algorithm will be shown in real-time. Visitors will also be able to see the real-time classification for their movements. A classification decision is shown in the last plot of the GUI as shown in Fig. 5.

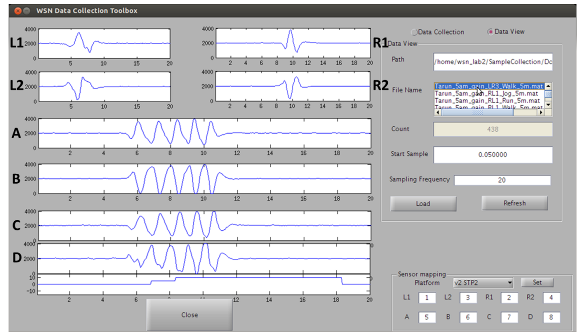

Fig. 5. Snapshot of the signals generated by the human walk at 5m from the STP.

4) *Web access to the features of the remote deployment:* An online demo of the deployment of the PIR sensor-based WSN at IISc by remotely accessing the web-based GUI of the system will be demonstrated. Some of the features as described in Section II will be exhibited to conference participants.

5) *Signal generation using animation for database:* A demo of PIRANA as explained in Section II will be presented. Conference attendees will be able to see the steps involved in developing animated $3D$ models and corresponding PIR signal generation. Fig. 6 illustrates the VPA generated by the STP and the animated models of human and animal.

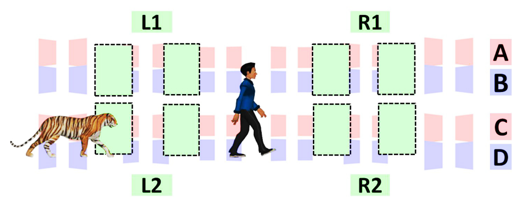

Fig. 6. The animated models of human and animal and the VPA generated at a vertical plane at a distance of 5 m from the STP.

V. Conclusion

Three important features will be demonstrated: (a) real time classification from a PIR sensor based platform, (b) online demo of the deployment of PIR sensor-based WSN at IISc by remotely accessing the web-based GUI of the system, and (c) an animation-based simulation tool for PIR sensor to simulate signals corresponding to human and animal intrusions. Demonstration will benefit the audience in building up the intuitive understanding about PIR sensor and learning about any WSN deployment in general.

References

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