Real-Time Implementation of Low Cost ZigBee Based Motion Detection System

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***Abstract*—Motion detection is a fundamental process that essentially detects a change in the position of an object with respect to its surrounding environment. It is highly demanding in various applications such as health care, defense and surveillance. The existing solutions for motion detection in indoor application are complex and expensive as it requires high end cameras and sensors. Hence, the objective of this paper is to provide an alternative cost effective solution. In the proposed motion detection system, Passive Infra Red (PIR) sensors are used to detect the presence of motion. The control unit of the PIR sensor transmits the trigger interrupt to the control unit of the camera via ZigBee communication. The rotational element present in the camera control unit rotates the camera in line of sight with the PIR sensor. The detected motion is then captured by the camera sensor and stored in Raspberry Pi, a microcontroller, which is then wirelessly transmitted to the receiver for further processing. The proposed motion detection system has been developed and validated in real time. It is observed that the performance of the developed system in terms of delay and QoS are acceptable for single event detection. However the proposed system can be extended for detection of multiple events.**

***Keywords*—Motion detection, ZigBee, Camera, Passive Infrared Sensor and real time implementation.**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are characterized by their networking capability, aggregated sensing, and distributed processing [5]. They are used in various civil as well as military applications. A target surveillance network typically consists of sensor nodes to monitor targets, collect the sensed data, and transmit them to a base station. These operations usually involve moderate energy usage.As the sensors are powered by batteries with limited energy, it is important to effectively manage their energy usage in order to ensure maximum lifetime of the nodes [8].

An organized and connected network covering the entire sensing field needs to be created using the sensors. Typical WSNs use disc based sensing fields with Omni directional sensors [9]. Due to cost consideration as well as the hardware design, sensors have sector-like sensing fields, which are known as directional sensors.

Directional sensors provide a narrow Field of View (FoV)due to their operating characteristics. But specific applications require the monitoring of large environments which may be beyond the FoV of these sensors. Hence, these applications require the use of multiple sensors to monitor entire environments. This method is usually cost prohibitive as well as constrained by other factors such as spatial requirements and temporal synchronization of aggregated data from the sensors. Hence a minimum number of sensors must be used in these situations in order to meet the above constraints.

In this paper, a Real-Time Implementation of Low Cost ZigBee Based Motion Detection System has been developed. This is based on an event triggered surveillance system. It consists of various sensors such as infrared detection sensors and a camera. The infrared detection sensor does motion detection while the camera records motion of the detected object with the aid of rotator element such as stepper motor. The camera sensor is rotated through various sectors of visual coverage, based on the data acquired from the infrared sensors.

From the aforementioned discussion, it is inferred that offering 'Maximum Sensing coverage with Minimum Sensor Deployment'is the most vital requirement for surveillance application. This in turn leads to reduction in cost of the application. Hence the objective of this research is to provide solution to meet the above mentioned requirements. It is known that the size of the camera lens determines the coverage area of the camera sensor.

Hence, to cover a wider area withthe minimum number of required sensors, the concept of Rotatable and Directional Sensors is adapted in the proposed work. By using directional sensors equipped with robotic actuators, as in stepper motors, these sensors are able to rotate,thereby providing spatiotemporal monitoring of the environment under observation.

Since most surveillance applications of remote environments require real time tracking of objects as well as successful transfer of these data, the issue of using the minimum number of sensors to reduce amount of data sent to the base station becomes even more necessary in execution of these setups.

The directional measurements for both the infrared sensor and the camera sensor are used to find out the Angle of View(AoV) as well as the Hyperfocal Distance (H),the equations for near distance (D_n) and far distance (D_f) have been derived as in [9] and used as a further reference.

$$\alpha_h = 2 \arctan \frac{h}{2f} \quad (1)$$

$$\alpha_v = 2 \arctan \frac{v}{2f} \quad (2)$$

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$$\alpha_d = 2\arctan\frac{d}{2f} \quad (3)$$

$$H = \frac{f^2}{Nc} + f \quad (4)$$

$$D_n = \frac{s(H-f)}{H+s-2f} \quad (5)$$

$$D_f = \frac{s(H-f)}{H-s} \quad (6)$$

Where (h, v, d) are the dimensions of the image sensor, c is the circle of confusion, h is the height, f is the focus, N is the f-number and s is the focus distance. Equations (1), (2) and (3) are used to calculate the horizontal, vertical and diagonal angle of view of the sensors (α_h, α_v, α_d). Equations (4), (5) and (6) are used to calculate the Hyperfocal distance of the camera.

Figure 1 showsa directional sensor node which senses a unit of sector described with the position (P), the working direction (W_d), the sensing radius (R_s), and the angle of view (α). A target (T) may be covered if it is located within the FoV of the node. It is found by the Target in Sector (TIS) test as explained in [9].

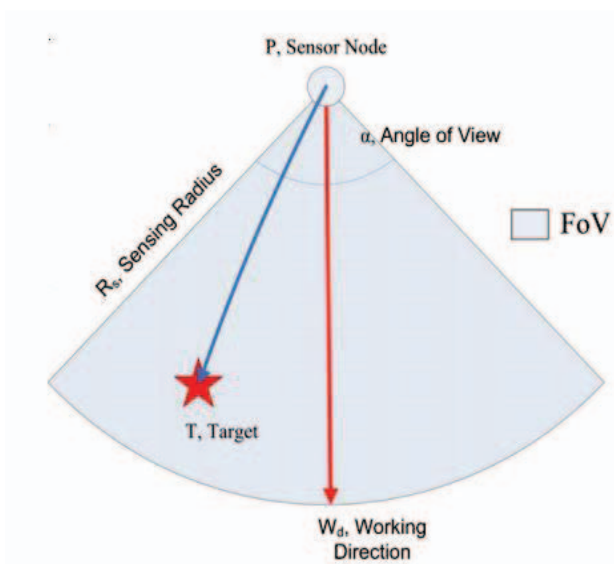

Fig. 1 Range of directional sensor

The rest of the paper is organized as follows. Section II provides a brief discussion on the existing work related to sensor coverage and video streaming. Section III describes the detailed system design.Section IV addressesthe practical implementation and system architecture. Section V contains the experimental evaluation and analysis of the setup. Section VI concludes the paper with possible future work.

II. RELATED WORKS

Ample amount of research work has been carried out in the field of sensor coverage as well as node placement scenarios.

A. SPATIAL COVERAGE

Chi-Fu Huang and Yu-Chee Tseng (2005) have addressed problems related to the coverage area in the case of directional sensors by reducing the coverage collision. However energy conservation of the sensor nodes has not been considered[2].

MihaelaCardei andJie Wu (2005) have surveyed the recent contributions addressing energy-efficient coverage problems in the context of static wireless sensor network.A brief focus has been made on the sensor deployment mechanisms based onnetwork parameters such as connectivity and energy consumption [11].

B. ENERGY EFFICIENCY OF SENSORS

Dietrich et al. (February 2009) has ascertained thatthe Sensor lifetime is dependent on factors such as availability of nodes,the sensor coverage,and the connectivity. The study has been performed for a simple situation and have not been extended to a more complex scenario [3].

Hai Liuet al.(2007) has compared the energy usage of various networks.From the investigation, it has been concluded that optimal and careful placement of sensor nodes ensures better performance. However, the work has been considered for static nodes and has not been extended to mobile nodes [6].

Jean Carle and David Simplot-Ryl(2004)have discussed a method of self organization of the sensor node to ensure the maximum monitoring time for the entire network. However only WSN of fixed broadcasting radii are taken into account and practical setting has not been discussed[8].

Hai Liuet al.(2007) has provided a solution to maximize the lifetime of sensor based surveillance system which is achieved through optimal routing protocol.The work has been implemented and validated for a heterogeneous scenario [7].

C. VIDEO STREAMING ANALYSIS

Reduced latency and increased throughput are the major challenges required in video streaming application. Adequate research has been performed in this field to achieve the aforementioned requirements. Several cognizing algorithms do exist in the literatures.

Mark Kalman et al. (2004) have developed a methodology to reduce the delay of real time video transmission. It adaptively changes the video playback speed to achieve this objective. The streaming model buffers media at the client, and combats packet losses with deadline-constrained Automatic Repeat Request (ARQ). Results have been obtained only for specific test cases under consideration [10].

RaspberryPi (2013) has stated the encoding formats as well as routing protocol utilized for Raspberry Pi programming. It has also considered the aspects of module development along with programming to create a prototype model for data collection. The development of the prototype has been elaborated in [12]. Wesley Chun (2006) has provided insights on practical aspects of Python Programming [13]. Eben Upton and Gareth Halfacree (2014) have imparted knowledge of hardware aspects of Raspberry Pi Prototyping [4].

This paper makes an attempt in the creation of a cost effective solution based on the amalgamation of existing works and present day hardware.

III. METHODOLOGY

The system model of the proposed motion detection system is presented in Figure 2. It consists of low power sensing nodes termed as End Device that does sensing of the motion objects. They are equipped with either Bluetooth or ZigBee transceiver module, through which the sensed information about the motion objects are communicated to the coordinator. The camera sensor present in the coordinator device has a rotating element which ensures synchronization between the end device and coordinator.

Initially, the information from all the end devices are transmitted to the coordinator device which is then aggregated based on which the orientation of the rotator element is decided. Thus, synchronization is ensured. Then, the presence of the motion object is captured by the camera sensor equipped in the coordinator device.

To ensure surveillance in real time, the captured information about the moving object that are stored in the coordinator device are transmitted to the local base station with the aid of high power communication technology such as WLAN.

The salient feature of using rotating element, results in usage of minimum number of sensors for motion detection application. Further, by adopting the concept of sleep/listen mode, the sensors that are not synchronized with the coordinator device are allowed to be sleep mode which make the application energy efficient. Thus the lifetime of the application can be prolonged.

Further, by using the standards such as H.264 and MPEG, the transmission time involved in video streaming from coordinator device to the local base station is very much reduced, which meet the fundamental requirement of real time surveillance application. The reliability of the application is also ensured with the aid of efficient error correction
mechanism.

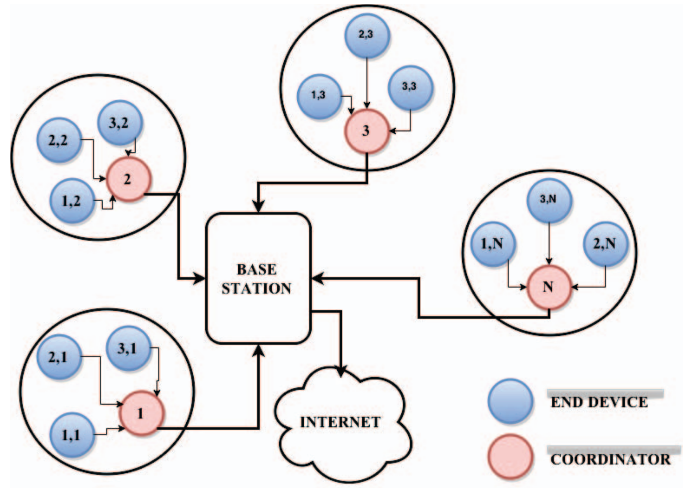

Fig. 2. System model of the proposed motion detection system

Two distinct types of sensors are used in the given setup. A PIR sensor is used for the purpose of human detection while a Camera sensor is used for visual identification of targets under detection.The nodes which together form network architecture similar to the cluster head architecture composed of cluster nodes which are characterized by the use of low power communication node connected to a PIR sensor node. The cluster head nodes are composed of a unique architecture composed of both a low power and a high power communication modem. This acts as a coordinator to ensure data aggregation among the end device nodes.

IV. IMPLEMENTATION SETUP

The Proposed motion detection system is model as a tertiary level cluster containing 3 cluster nodes which acts as end devices and 1 cluster head node which acts as a coordinator jointly forming an Ad-hoc network structure.

As shown in Figure 3, the end devices are composed of a combination of sensing element, microcontroller circuit and transceiver for data communication. The PIR motion detection sensor (HC-SR 501) is capable of detecting the presence of humans/ organic life forms based on changes in the surrounding heat. This is a low power sensor used for basic motion detection. The prototyping board utilized is an ‘Arduino UNO’ with a ‘ATMEGA 32U’ microcontroller chip. Signal conditioning and sampling of PIR Sensor data is performed by the chip.

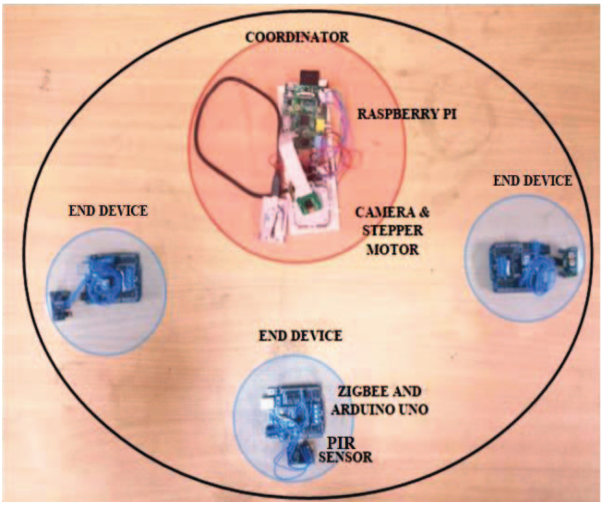

Fig. 3. System Architecture of the proposed motion detection system.

Figure 4, shows the system architecture of the proposed motion detection system. It comprises of heterogeneous sensor nodes. The Reduced Function Device (RFD) is the end device while the Full Function Device (FFD) is the coordinator.The RFD node consists of PIR sensor along with ZigBee communication module while the FFD consists of Camera sensor, rotating element (Stepper motor), Raspberry Pi (ARM 11) and a ZigBee communication module.

The transmitter is a device employing ZigBee (IEEE 802.15.14) protocol called as 'XBee Series 2'. The device has been set to use AT mode in an End Device configuration. Three such end devices are used in the setup and placed in 180 degree angle of coverage.

The microcontroller used in the coordinator is the Raspberry Pi which employs an 'ARM 11' processor for video capturing and streaming. The sensing device is a 'Raspberry Pi Camera' which is a single focus 5MP camera connected to the Raspberry Pi. It is capable of capturing videos at 720p resolution at 24 fps and is able to stream data to other nodes through the Raspberry Pi.

The receiver ZigBee node is connected to the Raspberry Pi and uses the API mode in a Coordinator configuration. It receives packet data which provides the transmitting node address and other diagnostic data to affirm the status of the node as well as the characteristics of the transmitting channel.

The portable setup consists of mounts for the Raspberry Pi, power source and a Stepper motor rated at 5v with 8 inbuilt poles for stepping action. This is controlled using the Raspberry Pi through its GPIO Pins. A WLAN (IEEE 802.11 n) standard capable node is in the setup. The node uses a maximum data rate of 54 Mbps without considering the effects of channel loss and data throughput.

Based on the data received from the Coordinator, the Raspberry pi changes the angle of orientation of the Pi Camera Setup, moving it towards the sensing area triggered by the End Device node. The Pi camera activates and sends the recorded video to Base Station where useful information is extracted from it. This is performed in a LAN environment using Socket Protocol. The security of the data transmitted to the Base Station is achieved through the WPA Access Control Mechanism of the WLAN Device and the encoded data from the Socket Protocol Mechanism. The base station is able to be connected to the Raspberry Pi Video Feed via a program coded for the receiving side. The video is viewed on conventional media players such as 'VLC Player'.

V. RESULTS

The verification and the performance analysis of the setup proposed in this paper have been carried out through hardware implementation. The experimental data is gathered from the PIR sensors and Camera sensor.

The results are validated based on the default readings extracted from the datasheet to analyze for any irregularities and errors. The effective range taken for the sensors has been kept within the lower limits of the error threshold.

Analysis of the delay in data transfer encountered in the network caused by live streaming of Surveillance video taken from the Camera Sensor has been logged.

The mean ping of the Internet Service Provider (ISP) is averaged to 40 milliseconds in both uplink and downlink. The averaged downlink speed at the client side is 21.2 Mbps and the uplink speed at the Server End of the network has been kept at 24.9 Mbps.

The latency of the video Transmission has a mean value of 1.8 seconds with a Standard Deviation value of 210 milliseconds. The values are calculated for the abovementioned network characteristics.

From the Figure 5, it is evident that the Responsivity of the PIR Sensor is maximum for the sampling frequency range from 0.1Hz to 0.2Hz. The Responsivity gradually decreases as sampling frequency increases from 0.2Hz. This is due to the fact that the sensor faces difficulty in distinguishing between different objects as detection time between two consecutive responses decrease. This is an inherent fault in the sensor itself and cannot be overcome.

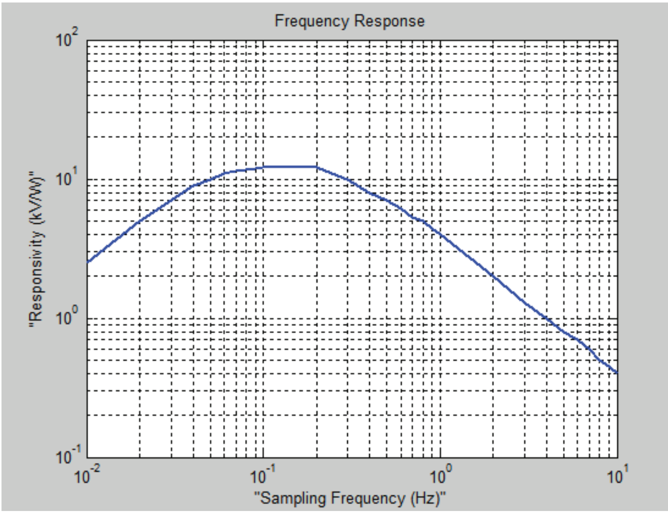

Fig. 5. Frequency response graph of PIR Sensor.

Energy conservation is also addressed as a part of system development. The PIR sensors, on detection of movement, interrupt the Raspberry Pi and causes camera to start recording. Thus, the camera is in active state only during the interval of sensed motion. Along with the camera, the WLAN communication module also transits to sleep state. Thus, overall energy consumption is reduced while the lifetime of the sensor nodes is increased.

VI. CONCLUSIONS AND FUTURE WORK

In this paper, a real time, cost effective solution to indoor surveillance has been developed. From the results obtained, it is inferred that effective usage of network resources, yields better system performance. The developed motion detection system is confined to 180 degree of orientation. However, it can be extended to 360 degree with six sensors when wider area of detection is required. By incorporating 3G technology with the developed system, a provision for remote access of detected data becomes possible. The developed setup mainly concentrates on single event detection. However it can be extended to multiple event detection scenarios.

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