# Real-Time Object Tracking in Wireless Sensor Network

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## Abstract

**Wireless sensor networks (WSNs) is a networked embedded system which comprises of spatially distributed nodes. Each node possesses sensing, processing and communication capabilities. This paper presents an object tracking method in wireless sensor network framework. The tracking system monitors trajectory of a moving object in real-time and determines exact location of the mobile entity. In proposed method, sensor node utilizes camera and distance sensors for object detection and an efficient tracking algorithm is incorporated for real-time object tracking using WSN paradigm. The location of object is continuously monitored by sensors and coordinates are timely communicated to the base station. The system nodes are active all the time for object detection while wireless communication between sensor node and base station is only performed if there is change in position of target object. The proposed WSN design utilizes star topology for communication between nodes and base station. The proposed method is tested for indoor object tracking and a comparison analysis of camera and distance based tracking is performed for different object trajectories and environmental conditions.**

## 1. Introduction

Wireless Sensor Network (WSN) consists of tiny sensor nodes capable of wireless communication that are deployed over different regions. The sensor nodes communicate with each other and are used for monitoring, surveillance and mobile object tracking. The information collected by the nodes is wirelessly communicated to the base station and is utilized for monitoring and tracking. The very first wireless sensor network, the SOSUS was developed by the United State Military in the 1950s [1]. Since then, a lot of work has been done; nonetheless most of the proposed methods lack accuracy or the sensor nodes consume energy due to continuous communication which reduces the network's life. In this paper, camera and ultrasonic sensor are used for tracking purpose. Both the sensors track the object simultaneously yet their tracking performance vary under different environmental conditions. The accuracy rate also depends upon the sensor node characteristics and WSN architecture. For example, changes in the light intensity greatly affect the performance of the camera. On the other hand, ultrasonic sensor performance remains unaffected. However, the ultrasonic sensor detection range is limited and these are used in different combination to enhance coverage of monitored region. In certain areas where human approach is difficult, the WSN is implemented to locate and track any foreign entity. In this paper, a wireless sensor network based framework is presented for mobile object tracking. Moreover, in this study the hurdles faced by the sensors in such unapproachable areas are discussed and the tracking performance of camera and distance sensors based tracking is investigated under different operating conditions to test the capability of the WSN. The proposed tracking approach have several advantages such as accurate and timely signal processing, increased system robustness and tracking accuracy. A review of the related work is discussed in section 2. In section 3, the proposed WSN framework based tracking method is presented. Section 4 details the implementation of WSN for mobile object tracking and section 5 discusses the comparison results for camera and ultrasonic sensors based tracking performance.

## 2. Related work

The camera based motion detection has become popular in monitoring and surveillance applications. Many researchers have proposed techniques to detect the moving objects. Singla [2] presented an object detection method using frame difference technique. The major limitation of this research work was that the camera continuously sends images and energy is consumed by the camera continuously. In [3], motion of the object is detected based on background motion detection method in which the current image is compared with the reference or background image pixel by pixel and when the number of changes in the pixel exceed the threshold value, motion is detected. Edge detection technique is another image processing technique used for object detection. Kang et al. [4] presented moving object detection method by incorporating overlapping of EO and IR sensors. This approach utilized the heterogeneous sensor nodes and Kalman filter stage. The performance of the system was assessed on several real video surveillance sequences. In [5] the shape measurement approach was used to locate the position of an object by using the ultrasonic sensor array. Collaborative signal and information processing (CSIP) was utilized in [6] to reduce the energy consumption. The basic principle used for tracking is object detection through sensors and application of the tracking algorithms to follow the mobile object movement path.

In object tracking applications where detection regions are spatially distributed wireless sensor networks (WSN) are employed [7-13]. In [7], a WSN based tracking method was presented in which the sensor nodes consists of passive sensors like proximity or PIR (heat sensor) sensors. The prediction or probability based tracking method was proposed in [8] using WSN architecture.

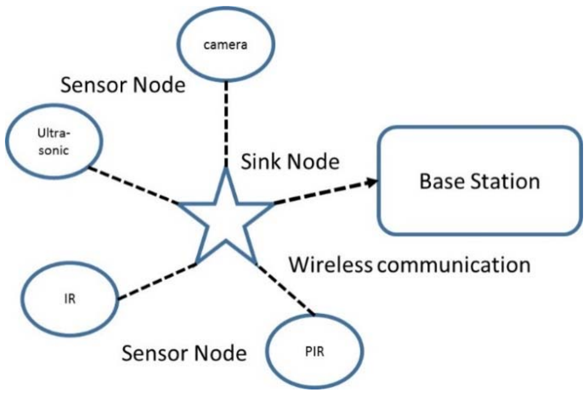



**Fig. 1.** Wireless Sensor Network Architecture

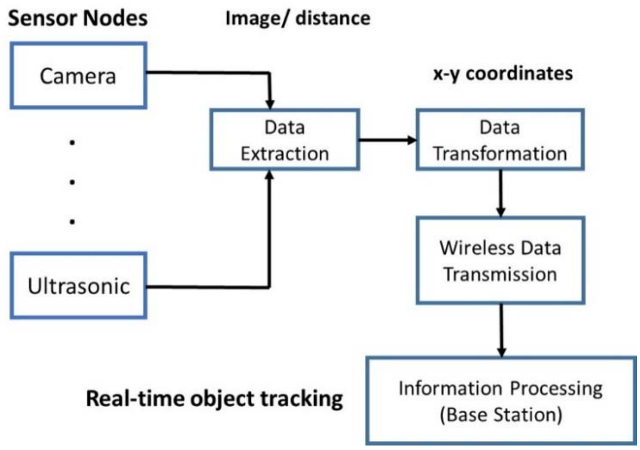



**Fig. 2.** Flowchart for object tracking in WSN using heterogeneous sensor nodes

## 3. Proposed Methodology

In this section, the proposed object tracking method in wireless sensor network (WSN) framework is presented. In proposed method, sensor nodes utilize camera and distance sensors for object detection. WSN architecture incorporated for real-time object tracking is shown in Fig. 1. The proposed methodology employees star topology in WSN framework where heterogeneous sensor nodes are wirelessly connected to a sink node/base station. The sensor nodes utilize different sensors for object detection and send the collected information to the sink node. If any sensor detects a moving entity within its vicinity, the location of the object is determined. The detected object's coordinates are sent to the base station and the trajectory of the path followed by the target object is retrieved at the base station end. If this object leaves the detection range of one node and enters the detection region of another node, the other node becomes active and starts tracking the object. In this way, the target object is continuously monitored in wireless sensor network with the miss rate nearly equal to zero. In other words, the sensor nodes in WSN work together to enhance the overall detection coverage. Moreover, the lifetime of the network is also maintained as all the nodes are not communicating with sink node all of the time rather only the active nodes communicate with the sink node. Therefore, the proposed WSN framework consume least amount of energy. The operation of proposed object tracking method in WSN paradigm is illustrated in flowchart of Fig. 2. The working details of camera and ultrasonic sensor nodes are discussed in the following sections.

### 3.1. Camera Node Object Detection Algorithm

The camera node consists of a webcam, processing unit and wireless transmission module. The object detection using camera node is illustrated in Fig. 3. The camera is deployed for image capturing and frames are further processed using Euclidean filter for object colour detection. The detected colour object frames are converted into greyscale images. Afterwards, a blob counter is used for data extraction (coloured object pixels). Aforge framework is utilized that provides useful features to count and extract stand-alone objects in images using connected components labelling algorithm. The algorithm treats all pixels with values less or equal to background threshold as background, but pixels with higher values are treated as objects' pixels. The counter detects all the selected colour objects. Out of these returned objects, the most prominent object is selected considering the case of single object tracking only. Finally, based on the object location in the image, the position of the object is determined i.e. dividing the distance over screen DPI, distance in inches is obtained.

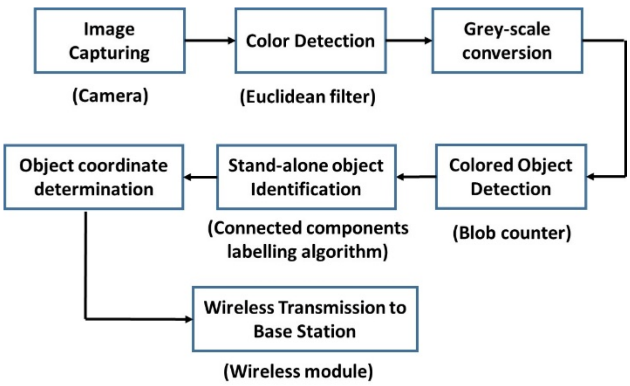



**Fig. 3.** Working of camera node in WSN

### 3.2. Ultrasonic Sensor Node Object Detection Algorithm

The ultrasonic sensor node consists of an array of ultrasonic sensors where individual sensors are installed with pre-defined orientation (line of sight). In order to provide comprehensive coverage of monitoring region, the ultrasonic sensor array is designed with overlapping detection zones with consecutive "N" individual sensors installed at pre-defined angular positions, refer to Fig. 4. The node works on the idea of obtaining polar coordinates $(r,\theta)$; where the component r is obtained from ultrasonic sensor value and $\theta$ is fixed for each individual ultrasonic sensor. Each sensor detects the object when it comes in its vicinity. The polar coordinates are determined based on ultrasonic sensor value and its corresponding $\theta$. If the object enters in the overlapping region of two consecutive sensors; the average value of two ultrasonic sensors and their corresponding average angles are incorporated to determine the fused polar coordinates of the object location. Afterwards, the polar coordinates are converted into respective rectangular coordinates using following equations:

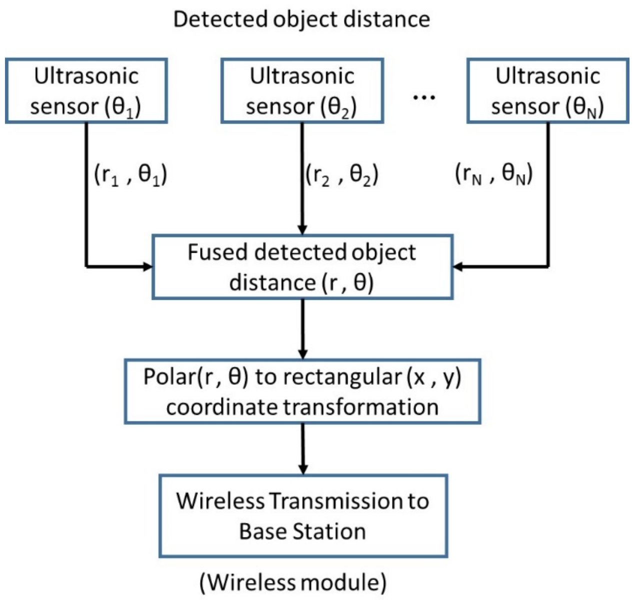



**Fig. 4.** Working of ultrasonic node in WSN

$$x = r\cos(\theta)$$
$$y = r\sin(\theta)$$

## 4. Implementation

In this section, the implementation details of the proposed object tracking methodology is presented. The wireless sensor network consists of camera and ultrasonic sensor nodes. According to the WSN star topology, the ultrasonic sensor node and a web cam act as the end devices used for getting object's position and the base station acts as a coordinator. The base station is used for the purpose of monitoring the final tracking results. The object tracking is performed in a pre-defined arena with 68 inches x 68 inches dimension. The proposed tracking algorithm performs real-time object tracking and focuses on the energy consumption issue during the process of tracking as well. Both the sensor nodes i.e. ultrasonic node and camera node perform object monitoring all the time but communication with the base station takes place only when the object enters the vicinity of the node. The object is tracked by the nodes onward and the coordinate information of the object's location is sent to the base station. The following section details the execution details of sensor nodes.

### 4.1. Ultrasonic Sensor Node

Ultrasonic sensor node is equipped with an array of HC-SR04 sensors (directional distance measuring sensor), an arduino UNO controller and Xbee series1 wireless communication module. In the designed sensor array, three sensors are deployed at three angular positions i.e. sensor 1 ($\theta_1 = 18^o$), sensor 2 ($\theta_2 = 43.5^o$) and sensor 3 ($\theta_3 = 65^o$); to have comprehensive coverage of arena. These sensors detects the object presence within specific directional detection zones. Nonetheless, gaps in the coverage are observed due to the directional nature of ultrasonic sensor which show that the object is not tracked accurately in some regions. For improved coverage, overlapping detection zones are incorporated and average of two consecutive sensors of the overlapping region is utilized in order to cover the gap and to accurately track the object. With presented ultrasonic sensor node design 30% of arena coverage is achieved. For wider coverage, the number of sensors (N) in the sensor array design should be increased.

### 4.2. Camera Node

The camera node covers about 70% area of the arena where camera is fixed at a height of 10 feet above the arena. The camera is controlled through the laptop via serial cable. The camera node is also equipped with an Xbee series 1 communication module which wirelessly connects the node to the base station. The camera captures frames every second which are displayed on customized Graphical User Interface (GUI). The pixel information is extracted and x-y coordinates of detected object are determined using the approach discussed in section 3.1. When the object enters the arena with respect to a reference point (entrance point), camera starts the tracking process. Once the object is detected, the object's coordinates are displayed on the GUI. The real-time changes in x-y coordinates (as long as the object is moving) are displayed on the screen and the real-time trajectory followed by the object is sent to the base station wirelessly through the communication module.

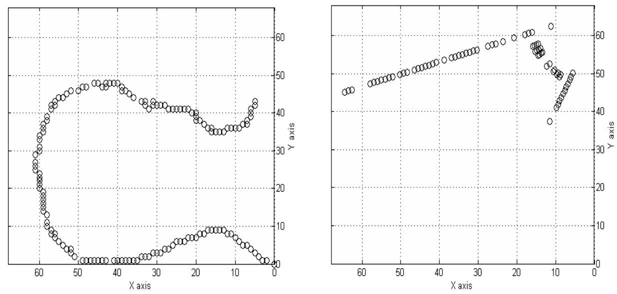
The base station is data center and the final end user interface for display and analysis of object trajectory where the user sitting in remote area can monitor the object. The data sent by the sensor nodes is received at the base station using IEEE802.15.4 standard communication protocol. The base station is equipped with Xbee series-1 module configured as coordinator for receiving data and sending broadcast to the end devices.

## 5. Tracking Results

In this section, camera and ultrasonic sensor based tracking results are compared for three trajectory cases. The camera node covers about 70% of the arena whereas the ultrasonic sensor node is designed to provide the remaining 30% arena coverage. The targeted tracking object is remote controlled car which follows different trajectories under varying light intensity conditions. The real-time tracking results for three different cases are discussed in the following.

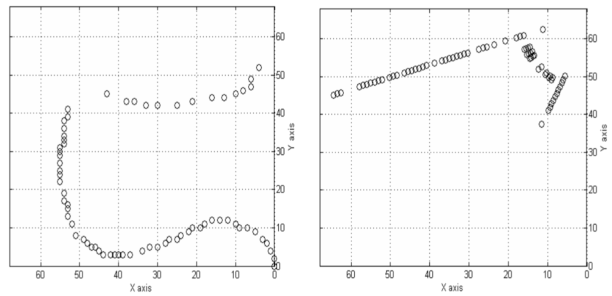
### 5.1. Case 1- Object tracking under normal light

In the first case, object tracking is carried out using camera and ultrasonic nodes under normal light conditions. The tracking results of both nodes are shown in Fig. 5. The car enters the arena at the point (0, 0), which is taken as reference point. The car continues to move in the arena and its path is tracked by both the nodes within their respective coverage regions. The Fig. 5(a) shows the camera tracking results under normal light with accurate tracking performance within its designed coverage range.



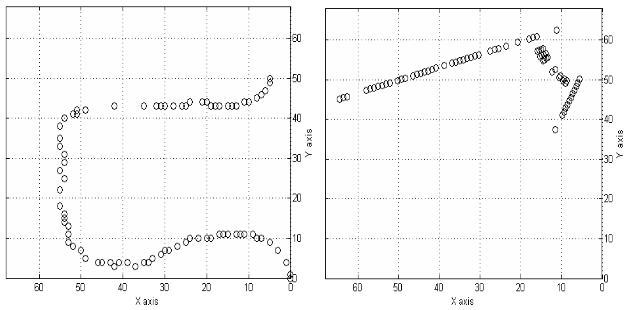

a. Camera tracking results b. Ultrasonic tracking results

**Fig. 5.** Object tracking results for Case 1



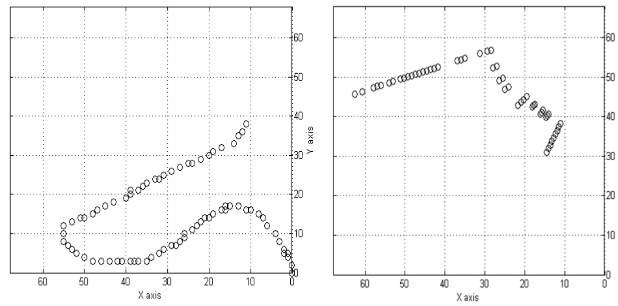

a. Camera tracking results b. Ultrasonic tracking results

**Fig. 6.** Object tracking results for Case 2 (dim light)




a. Camera tracking results b. Ultrasonic tracking results

**Fig. 7.** Object tracking results for Case 2 (bright light)




a. Camera tracking results b. Ultrasonic tracking results

**Fig. 8.** Object tracking results for Case 3

The ultrasonic sensor is a distance measuring sensor and its performance is not affected by the variations in light, refer to Fig. 5(b). This sensor node tracks the object when it enters its coverage region. The three sensors are already in the active mode. The car enters the ultrasonic sensor's region at the point (11, 37). When the car comes into the vicinity of sensor 1, it is detected by the sensor and information about object coordinates ($r_1$, $\theta_1$) is obtained. At the point (9, 50), the car enters the detection zone of sensor 2. Now the distance information of sensor 2 i.e. ($r_2$, $\theta_2$) is utilized. At the point (11, 63) the car is detected by the sensor 3 and now sensor 3 distance and angle ($r_3$, $\theta_3$) is used for x-y coordinate transformation. When the object is overlapping sensor regions, the fused polar coordinates ($r$, $\theta$) are computed using the data average technique explained in section 2.2.

## 5.2. Case 2- Object tracking under extreme light condition (dim, bright)

In this case, tracking results of camera and ultrasonic sensor nodes are obtained under extreme light conditions i.e. bright light and dim light. The tracking results are generated for the same trajectory as given in case 1.

### 5.2. (a) Tracking results under dim light

Dim light affects the performance of the camera and it becomes difficult to locate the car position accurately. Fig. 6(a) shows gaps in camera monitored trajectory from the point (43, 46) to (53, 41). The gaps are due to the dim light in this particular region where the camera is unable to locate the object. Hence, object x-y coordinates are not communicated to the base station and data-outage is observed in the graph for this region. The ultrasonic sensor node tracking results are the most accurate in this case as it can track the object without missing any coordinates as shown in Fig. 6(b). The ultrasonic tracking results are similar as in case 1 because actual object trajectory remains unchanged and light has no effect on the performance of ultrasonic sensor so the miss rate here is nearly equal to zero.

### 5.2. (b) Tracking results under bright light

The camera and ultrasonic sensor monitored trajectories are shown in Fig. 7(a) and 7(b) respectively. In Fig. 7(a), data-outage is observed in the camera monitored trajectory at points (48, 41), (43, 43) and (35, 43). Due to the bright light, it becomes difficult for the camera to focus and locate the exact object position. As the object is not located by the camera within (48, 41) to (43, 43) and (43, 43) to (35, 43) regions, x-y coordinates are not communicated to the base station and hence the graph shows gaps for this region. Once again, the trajectory traced by the ultrasonic sensor is not affected by the light.

## 5.3. Case 3- Object tracking with changed trajectory

In case 3, object tracking results for camera and ultrasonic sensor node are generated in the normal day light on a completely changed trajectory. In the Fig. 8, the trajectory followed by the object is illustrated. It is clear from the Fig. 8(a) that a fine camera monitored trajectory is achieved where the tracking accuracy is near 100%. On the other hand, a changed trajectory affects the performance of the ultrasonic sensor. The result in Fig. 8(b) shows that the car is now far from the ultrasonic sensor node and it becomes difficult for ultrasonic sensor node to track the object. There are gaps in the graph which show reduced tracking performance of ultrasonic sensor at far distance region. Therefore, tracking performance of ultrasonic sensor node depends on sensor node design, number of sensors 'N' in sensor array and angular position of sensors within the sensor node.

## 6. Conclusions

This paper presents an object tracking method in wireless sensor network framework. The tracking system monitors trajectory of a moving object in real-time and determines exact location of the mobile entity. In proposed method, sensor node utilizes camera and distance sensors for object detection and an efficient tracking algorithm is incorporated for real-time object tracking using WSN paradigm. The proposed method is tested for indoor object tracking and a comparison analysis of camera and distance based tracking is performed for different object trajectories and environmental conditions.By comparing the tracking results of the sensor nodes under different conditions, it is inferred that the tracking performance of camera sensor node is only affected by the variation in light. On the other hand, the tracking performance of ultrasonic sensor is affected by the sensor array design and number of sensors in the ultrasonic sensor node. However, the major advantage of this system is the deployment of heterogeneous sensor nodes for dynamic response as opposed to typical traditional target tracking systems that deploy homogeneous sensor nodes.

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