A Framework for Sensor Management in Wireless and Heterogeneous Sensor Network

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Abstract

This paper proposes a framework for sensor configuration and management in wireless multi sensor network system, which is responsible for taking decisions in order to coordinate the assignment and scheduling of sensors best suited for the application.

A Sensor Manager operates over a heterogeneous sensor network which provides sensory data from multiple types of sensors. The application of this work is tracking the movement of objects in a moderately occupied confined space. Simulations were run to study the operations of the proposed sensor manage in such application. The simulation results are compared to other published results to show the effectiveness of this work.

1. Introduction

The wireless sensor networks (WSNs) is an emerging technology that provides ubiquitous sensing and computing capabilities through which objects can more closely interact with the environment. With recent advantages in sensing and wireless communications, it is possible to construct a network consisting of a large number of heterogeneous sensing devices.

Typically these networks comprise a large set of tiny electronic, low power sensors scattered over the area to be monitored. The sensors have the ability to sense the environment in various modalities, process the information, and forward it to a central node for further processing.

If the ability of the WSNs is suitably harnessed, it is envisioned that the WSNs can reduce or eliminate the need for human involvement in information gathering in broad civilian or military applications such as national security, health care, environment protection, energy preservation, food safety, and so on [1]. However, the need to coordinate such large networks as well as their inherent limitations like power constraints, limited bandwidth, distributed coordination and ad hoc deployment lead to a number of challenges in the design and deployment of a network. In order to simultaneously satisfy these requirements and constraints, and improving the overall efficiency, we need large scale coordination and management operations.

The organization of the rest of the paper is as follows. In section 2, we present the Organizational and Architectural Framework for our Intelligent Sensing System. Section 3 gives a brief review on current research. Section 4 describes the research challenges and formulates the problem. A solution approach is proposed in Section 5. We then present, in Section 6, the simulation results, and compare the proposed method to a base method in which every sensor periodically reports data to the central unit. Section 7 concludes the paper and outlines directions for future work.

2. Organizational and Architectural Framework

The following Figure 1 shows the framework of the

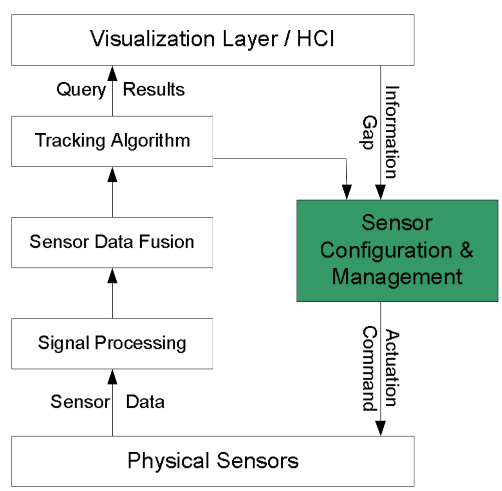

Figure 1. Unified Sensing System Model

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Unified Sensing System Model. The model places the physical layer of sensors at the bottom of the hierarchy. The raw data from the sensors are sent to the signal-processing layer, from which data are sent to the data fusion layer. The tracking algorithms use the fused data to compute such information as position, speed, and movement direction of the targets. The user gets visual representations of the object information under tracking as well as deployment status of the physical sensors. The visualization layer also receives commands from the user and passes the inputs to the sensor configuration and management layer.

There are multiple levels of fidelity the user desires according to the need of the application. Hence, task of the sensor management layer is to provide the desired level of fidelity at a minimum cost.

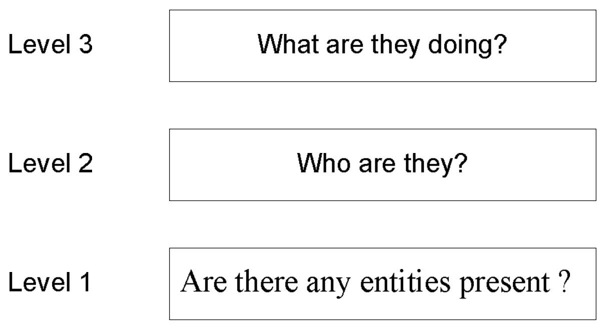

Figure 2. Levels of fidelity

The sensor management engine takes this location information and schedules the activation of the sensors. If there are multiple objects present within the sensing range of any one of the sensors, then the sensor managing system keeps track of them, considering it to be a group of objects. There are multiple levels of fidelity that the user can require from the system.

For example, if an object starts moving away from the group and the user wants to know who moved away, the sensor manager issues a command to activate the camera in that area and check the identity of the object.

Should the user require higher fidelity, e.g., to determine the identity of the objects present in a given area, then the sensor manager again issues a command to turn on the cameras in that particular area. If an interested entity is identified, the sensor manager will be responsible for "deciding what sensors to activate" to keep a close track of the object.

3. Related Work

One of the first articles to apply optimization technique to sensor management problem is by Nash [2] in which he uses linear programming to determine sensor-to-target assignment for targets being tracked. Several recent papers have been investigating the application of Information Theory in order to develop a metric that a sensor management system can use to perform energy to quality trade offs [3]. Perillo [4] tries to solve the problem by modeling it as a generalized maximum flow problem.

SPAN [5] proposed by Chen et al., allows smart sensors to be turned off when they are not being used as a traffic source or are playing a vital role in collecting environmental information.

An information-driven sonar collaboration mechanism is proposed by Zhao [6]. It is quite similar to our approach, but they do not handle a heterogeneous sensor network nor discuss the challenges involved in multiple target tracking. Another approach, which also similar to ours is by Sikdar [7] where he proposes a protocol for tracking moving targets using a wireless sensor network, he does not address the issue of how to maintain the identity of two targets if they are moving very close to each other.

There exist two main approaches for handling multiple-target tracking in the literature: the multiple hypotheses tracking (MHT) [8] and the joint probabilistic data association filter (JPDAF) [9]. These two approaches were originally constructed for a sensor network consisting of only a single type of sensors.

Reliable tracking of targets using sensors placed throughout the confined space involves knowing the locations of the targets present in that space. Over the years, many location estimation approaches have been introduced using sensors such as range finders, sonar, radar sensors, cameras, etc. These sensors provide accurate location information, but do not provide any explicit information about the identity of the entity being tracked. On the other hand, visual sensors such as cameras do provide explicit identity information about the entity, but very coarse information about its location. Also, the amount of the battery power and bandwidth needed for sending the data from these visual sensors is considerably high as compared to sonar sensors.

Various techniques have been proposed for sensor management schemes employed in tracking with multiple range finding sensors like sonar, radar, acoustic sensors or multiple visual sensors such as cameras, while much of the research work done in this area attempts to minimize the power consumption by reducing communication, the problem of coordination of heterogeneous sensor network which integrates sonar as well as visual sensors and reduces the network bandwidth consumption has not been addressed so far.

In light of this, we design our management layer that utilizes the complimentary strengths of sonar as well as visual sensors.

4. Problem Description and Formulation

4.1 Problem Description

The confined space, in which we are performing tracking and surveillance tasks, is divided into several zones and has a tight relationship with the sensor manager. Each zone contains event-detection sensors, sonar sensors and visual sensors for e.g. Camera. The hierarchy of the surveillance zone is shown in Figure 3.

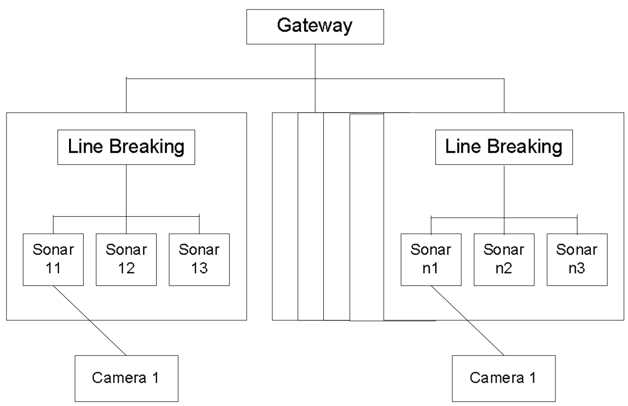

Figure 3. Hierarchy of the surveillance zone

Layer 1: Gateway. A sensor node with more computat-ional power and resources.

Layer 2: Event driven sensors. This layer is responsible for activating corresponding layer 3's sensors.

Layer 3: Range sensors. Sonar sensors are responsible for detecting object's position. The sonar sensors can only get the radial distance between object and sonar sensor.

Layer 4: Camera and acoustic sensors.

The problem is to develop an intelligent sensor management system for the wireless sensor network shown above which requires minimum battery consumption and minimum bandwidth as well as preserving the quality of tracking.

By quality of tracking we mean that the system should be able to tell which object went in what direction and to determine if someone is present in this area.

From the line breaking and sonar sensors data, the system is to project the next position of the object, with the time series trajectory of his path. Based on that computed next position, it sends commands to activate the sonar sensors in that region.

When this method is extended to tracking multiple objects, as opposed to tracking a single object, it works just as accurately if the objects are moving with a considerable distance among them. However, it introduces additional problem of *data association* if the two objects are moving very close to each other [10]. More generally, the effect of multiple objects within the range of a sonar sensor is that the measurement observed by the sensor, contains values of all individual contributions of the objects present. Thus, the problem of the system is to determine which part of the sensor measurement belongs to which specific object.

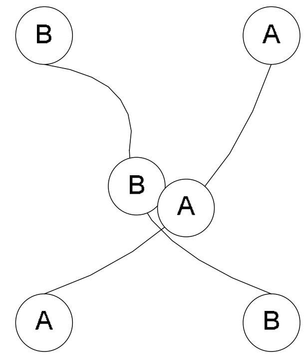

Figure 4. An example of data association

4.2 Problem Formulation

Let there be N objects present in a confined space. The location of each object at time t is given by $X_{si}(t)$, $Y_{si}(t)$, where $i = 1$ *to* N.

The next location of each object at time $(t+\Delta t)$ is predicted to be $X_{pi}(t+\Delta t)$, $Y_{pi}(t+\Delta t)$.

Given $X_{pi}(t+\Delta t)$, $Y_{pi}(t+\Delta t)$ and sensing range r, find the next set of k heterogeneous sensors such that they minimize the energy expenditure $P(t)$ and minimize the error in their position $E(t)$. The error is given by the Euclidean distance between the actual position of the object and the predicted position.

Predicted position of the ith object:

$(X_{pi}(t + \Delta t), Y_{pi}(t+ \Delta t), r)$ $i = 1$ *to* N

Next set of heterogeneous sensors to activate:

$\{S_j\}$ $j = 1 \ldots k$

Such that:

$\min P(t) = Power(\{j\})$

$\min E(t) = Error((X_{si}, X_{pi}), (Y_{si}, Y_{pi}))$

$P_j(t) < \max P_j$, *where* P_j *is the power consumed by the sensor i.*

$(X_p(t + \Delta t), Y_p(t+ \Delta t), r)$ => *Find* $\{j\}$ $j = 1..k$ *(k can be sonar as well as camera sensors) such that* $\min P(t)$ *and* $\min E(t)$.

5. Solution Approach

Single Target

There are a total of T sonar sensors in the sensor network that will be used for tracking the movement of the target. At a given time t, there are a constant k sensors which are activated and are used in detecting the target. This set of k sensors is given by $\{S_{ON}(t)\}$.

In order to track the object's path, we will assume that we know the physical location of each sensor. The location of each sensor is given by $S_j = (x_j, y_j)$ where $j = 1\ldots\ldots n$.

Each sensor is able to detect the existence of nearby moving objects. We assume that the sensing scope is r. Within detectable distance r, a sensor is able to determine its distance to an object.

We assume that three sonar sensors are sufficient to determine the location of an object. Specifically, suppose that at time t the sensors S_1, S_2 and S_3 are used to detect the object, and that the distances to the objects detected by these sensors are $r1$, $r2$ and $r3$. The position of the object at time t is given by the intersection of the circles centered at S_1, S_2 and S_3.

From previous location, $(X_s(t-\Delta t), Y_s(t-\Delta t))$, and current location $(X_s(t), Y_s(t))$, we can predict the next location of the target at $t + \Delta t$ as : $(X_p(t + \Delta t), Y_p(t + \Delta t))$ using the velocity and direction of motion of the object. The velocity is given by:

$$v = \frac{\sqrt{(Xs(t) - Xs(t-\Delta t))^2 + (Ys(t) - Ys(t-\Delta t))^2}}{t - (t - \Delta t)}$$

Direction $\theta = tan^{-1} (Ys(t) - Ys(t-\Delta t) / (Xs(t) - Xs(t-\Delta t))$

We can calculate:

$$X_p(t+\Delta t) = X_s(t) + V \times cos\theta \times \Delta t$$

and $$Y_p(t+\Delta t) = Y_s(t) + V \times sin\theta \times \Delta t$$

The set of k sensors is selected such that the Euclidean distance D

$D(S_j(xj,yj), Predict(X_p(t + \Delta t), Y_p(t + \Delta t))) < r$
(r = *sensing range of sonar sensors*)

Multiple Targets

If the two or more objects moving in the confined space are far away from each other, then the tracking is similar to a single object moving.

It is only when there are two or more objects moving very close to each other, that there is ambiguity in the data acquired from the sonar sensors. In such a situation, the visual sensors come to our aid. The complete flow chart for the sensor management system is shown below:

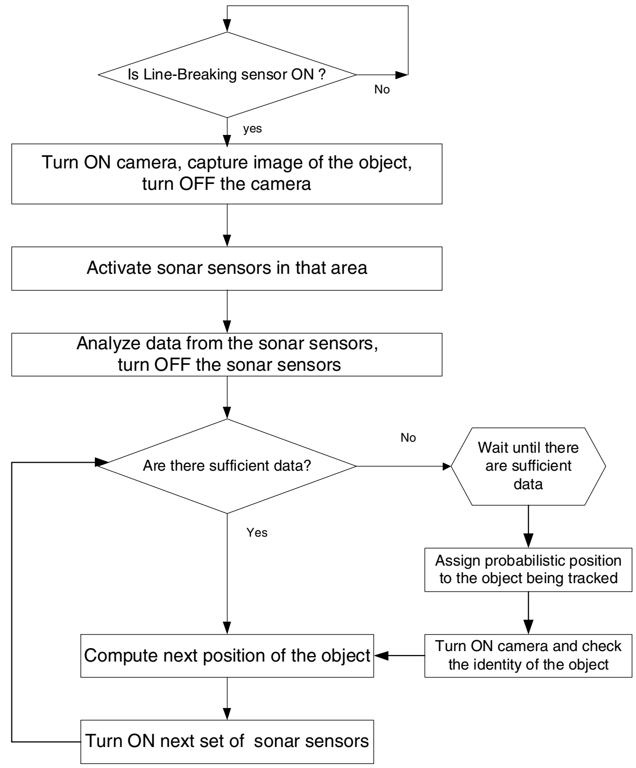

Figure 5. Sensor management flow chart

Energy Consumption

Suppose a sensor has 3 basic energy consumption types [11].

1. Sensing / Receiving Mode
2. Transmitting Mode
3. Sleep Mode

These modes are denoted by $\lambda^* E_r$, $\lambda^* E_t$ and $\lambda^* E_s$ respectively, where λ is proportional to the sensor type. For visual sensors λ would be higher than for sonar sensors because visual sensors consume more battery power than sonar sensors. Also the bandwidth required for transmitting visual data is higher than the bandwidth required for sonar data.

The power consumed by the sensors in the sleep mode or when they are of is assumed to be negligible. Hence, if at any given instance t there are k sensors used in detecting N objects, then the power consumed for the sensing activities in the surveillance zone is given by:

$$P_r(t) = \sum_{j=1}^{k} \lambda E_{r_j}(t)$$

The power spent in transmitting the sensed data to the sensor manager is given by:

$$P_t(t) = \sum_{j=1}^{k} \lambda E_{r_j}(t)$$

Hence the total power consumed by the sensor network during time t is given by:

$$P(t) = P_r(t) + P_t(t)$$

For a total of surveillance time T, the power consumed by the system is given by:

$$P_{Total} = \sum P(t)$$

6. Simulation Results

We present simulations demonstrating our approach for single and multiple target tracking using MATLAB.

6.1 Simulation Setup

The simulation is done on a 60 meters by 60 meters confined space considered to be the sensor field. The targets move randomly in this two-dimensional sensor field. The speed of the targets is varying between two m/s to eight m/s. The sonar sensors are placed uniformly in the sensor field grid. The range of each sonar sensor is 6mts and the angular distance it can cover is 60 degrees. There are a total of 181 sensors placed in the sensor field.

The energy consumption of the sensors is measured in Joules/sec (Watts). For the sonar sensors, the initial battery life of all the sensors is set to be five Joules.

The energy consumed when the sensor is in transmitting or receiving mode (E_r and E_t) is assumed to be 10µJ/sec. Thus $E_r = E_t =$ 10µJ/sec. For the camera sensors, the battery consumption is higher than the sonar sensors. Hence we assume $E_r = E_t =$ 1000µJ/sec for camera sensors.

Single Target

We show the case for a single target tracking. Given the current position of the target from the target tracking module, the sensor manager estimates its next position and locally determines the optimal set of three sensors to activate, such that we can get the accurate position information of the target. We add White Gaussian Noise to the data received from the sensor and send it to the central control unit for further processing.

The figure shows the layout of the confined space. The dots (*) indicate those sensors that are in sleep mode. The three dots (◊) in the figure indicate those sensors that are activated at a particular instance.

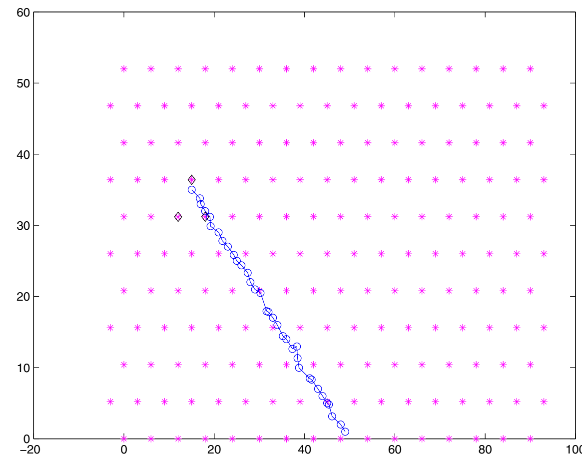

Figure 6. Snapshot of simulation for tracking a single target

Since there is no ambiguity in the data to estimate the target track, we do not need any visual sensors to be activated. Thus, we are saving energy and the network bandwidth by not turning on the visual sensors.

Two Targets

Step 1:

Both targets arrive in the surveillance zone at time t = 1. The targets are 35 meters apart from each other. The sensing range of each sonar sensor is six meters. Based on their current location information, our prediction algorithm gives an estimate of their next position. The system determines which sensor nodes are within the range of the target and turns on those sensors.

The three sensors that are closest to the target are used to determine the next position of the target. Note that the sensors in the region, which are not within the sensing range for the targets, are not turned on.

There are total six sensors on at any instance t, which are being used for tracking target 1 and target 2.

Step 2:

As both targets start getting spatially close to each other, it is possible for a single sensor to return two sets of data that contain the position information for both targets. In order to demonstrate the points where there is discriminatory information between crossing targets, we halt the system.

Also note that the number of sensors used for tracking has been reduced from 6 to m (m<6 and m>=3) if both targets are within the sensing range of m sensors so that they can provide two sets of data to triangulate the position of each target. Thus we are conserving the battery life, by reducing the number of sensor activated.

Since the targets are moving too close to each other, we assume that we are tracking them as a group of entities. As discussed earlier, it is outside the scope of the sensor management module to accurately track the position of each and every entity since that function will be handled by the tracking algorithms. We are only providing the scheduling of sensors.

Step 3:

The case when there exists discriminatory information between crossing targets but that information cannot be exploited until after the targets have diverged again, can be dealt with initially in the same manner as the case when there exists no discriminatory information. That is there is no pause in our simulation.

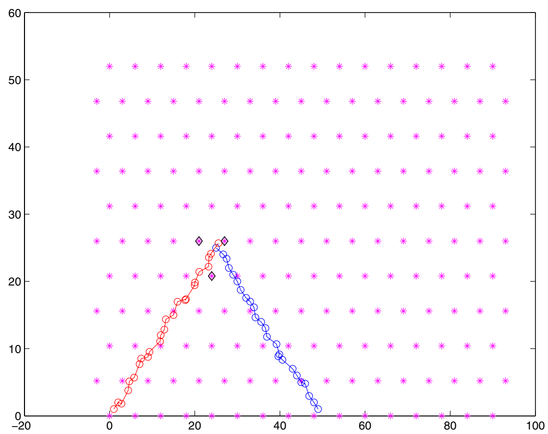

Figure 7. The targets come close to each other

At this instance we can again turn on the cameras to verify the identity of the target.

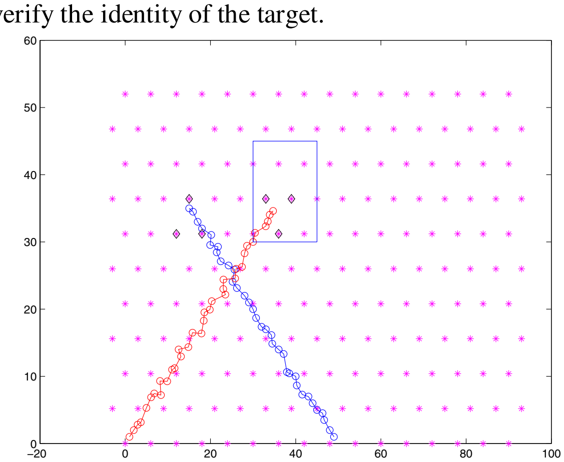

Figure 8. Camera activated to resolve the ambiguity

We consult an expert system, where the physical characteristics of the targets are stored when the object first enters the sensing zone.

Multiple Targets

The abovementioned can be extended to three or more targets. The following figure shows the snap shot of the simulation for 3 targets.

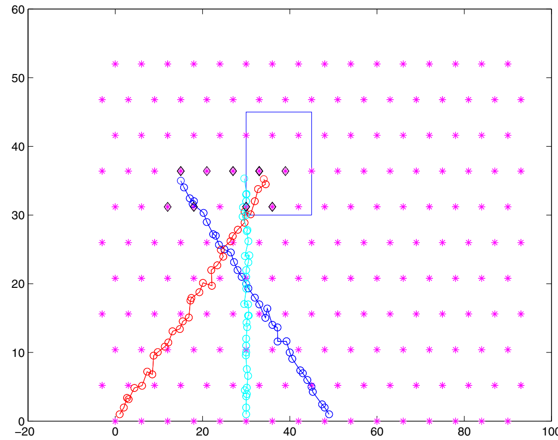

Figure 9. Tracking 3 targets with camera on

6.2 Energy Consumption

In order to show the energy or power savings of the wireless sensor network, we calculated the total power consumed at every time step by all the sensors that were active at that time interval. Since the power consumed by the line breaking sensors and the sonar sensors when they are not active is almost negligible as compared to when they are in active mode, we only calculate the E_r and E_t of the active sensors and their summation gives the power consumed by the wireless sensor network in µJoules.

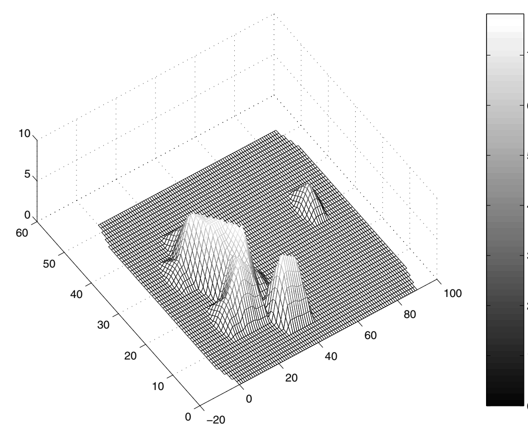

Figure 10. Height map of sensor usage

The figure shows the sensor usage of the sensor network. It shows which sensor was in active mode and

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for how long. More specifically, it shows the ON time of each of the sensor present in the sensing field.

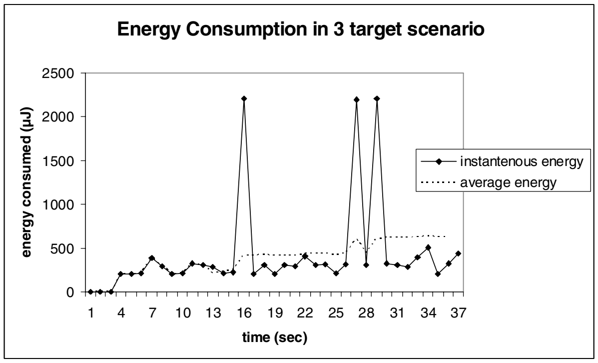

Figure 11. Energy Consumption of the Wireless Sensor Network in 3-target scenario

Figure 11 shows the energy consumption of the wireless sensor network when there are multiple targets/entities present in the sensing field. As we can see from the figure, only 9% of the total sensors are used when there is only one object moving in the sensing field. We can also see the energy consumption is constant at 60 µJ when there is only single target present. This is due to the fact only the sonar sensors are used to detect the presence and movement of the object. Since there is no need for activating any camera sensors, the energy consumption remains constant.

In case when there are two or three or more targets present, there is a need for the sensor manager to issue commands to activate the camera sensors. Since the camera sensors consume more battery power than sonar sensors, we can observe an increase in the energy consumption of the wireless sensor network whenever the camera is turned on.

6.3 Comparison of Energy Consumption

Method that we are comparing with is *Randomized Activation* [11]**.**

In this strategy, each sensor node is ON with a probability p. On average a fraction p of all the nodes will be ON and in tracking mode.

In this case, the energy consumed is given by

$$P(t) = p \times N \times E_r$$

The following chart is a comparison of energy consumption for tracking a single target. Our proposed method uses only uses 13% the energy as needed by the method of *Randomized Activation***.**

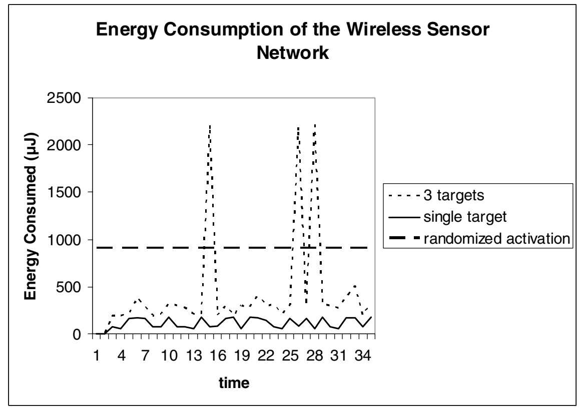

Figure 12. Comparison of the Energy Consumption in different scenarios

7. Conclusions

In this paper, we have proposed a feasible method for scheduling and activation of sensors in a multi-type wireless sensor network while preserving the quality of tracking. We achieve a significant reduction in power consumption using our approach as compared to Randomized Activation. It should be noted, that in our approach, we are relying on the Image Processing Algorithms for removal of ambiguity related to the target. Many real time systems have been developed for tracking objects, each varying in function and detail. Most of these methods for tracking objects in image sequence use color, contour tracking and/or motion. The current image processing literature shows that the objects/entities in an image can be successfully identified if multiple subjects are not near each other or they are not occluded due to shadow or lightning changes. Hence, our tracking mechanism will not be effective in a densely occupied environment

As future work, we will implement more advance image processing algorithms, which can identity the objects in a cluttered environment. Another direction to look at is to consider the failure of sensor nodes, which are used in the wireless sensor network. In the present work, we are not considering the scenarios of sensor node failure. Thus, the proposed system can be extended for surveillance and tracking in a cluttered environment.

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