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# Target tracking in wireless sensor networks

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# TARGET TRACKING IN WIRELESS SENSOR NETWORKS

A Thesis

Submitted to the Graduate Faculty of
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science in Electrical Engineering

in

Department of Electrical and Computer Engineering

by
Tarun Anand Malik
BE in Computer Science and Engineering, Maharshi Dayanand University (India), 2003
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## ABSTRACT

The problem being tackled here relates to the problem of target tracking in wireless sensor networks. It is a specific problem in localization. Localization primarily refers to the detection of spatial coordinates of a node or an object. Target tracking deals with finding spatial coordinates of a moving object and being able to track its movements.

In the tracking scheme illustrated, sensors are deployed in a triangular fashion in a hexagonal mesh such that the hexagon is divided into a number of equilateral triangles. The technique used for detection is the trilateration technique in which intersection of three circles is used to determine the object location. While the object is being tracked by three sensors, distance to it from a fourth sensor is also being calculated simultaneously. The difference is that closest three sensors detect at a frequency of one second while the fourth sensor detects the object location at twice the frequency. Using the distance information from the fourth sensor and a simple mathematical technique, location of object is predicted for every half second as well. The key thing to note is that the forth sensor node is not used for detection but only for estimation of the object at half second intervals and hence does not utilize much power. Using this technique, tracking capability of the system is increased.

The scheme proposed can theoretically detect objects moving at speeds of up to 33 m/s unlike the paper [16] on which it is based which can detect objects moving only up to speeds of 5 m/s.

While the earlier system [16] has been demonstrated with four sensors as well, but for that the arrangement of sensor nodes is a square. The technique demonstrated does not involve a change in the arrangement and utilizes the hexagonal mesh arrangement.

Some other scenarios have been tackled such as when displacement of the object is zero at the end of one second. Its movement is predicted during that time interval. Also, incase an object moves in a circle, such motions are also tracked.

# 1. INTRODUCTION

## 1.1 Background

Wireless communication and MEMS - the two technologies which have revolutionalized the way we live have also resulted in the development of wireless sensor networks. These comprise of relatively inexpensive sensor nodes capable of collecting, processing, storing and transferring information from one node to another. These nodes are able to autonomously form a network through which sensor readings can be propagated. Since the sensor nodes have some intelligence, data can be processed as it flows through the network. The latter is being done wirelessly these days using networking principles. The flexibility of installation and configuration has greatly improved resulting in a flurry of research activities commencing in the field of sensor networks owing to their ready acceptance in various industries such as security, telecommunications and automobile to name a few.

By early next century, sensor integration, coupled with unceasing electronic miniaturization, will make it possible to produce extremely inexpensive sensing devices. These devices will be able to monitor a wide variety of ambient conditions: temperature, pressure, humidity, soil makeup, vehicular movement, noise levels, lighting conditions, the presence or absence of certain kinds of objects, mechanical stress levels on attached objects and so on. These devices will also be equipped with significant processing, memory and wireless communication capabilities. Emerging low-level and low-power wireless communication protocols will enable us to network these sensors. This capability will add a new dimension to the capabilities of sensors: Sensors will be able to coordinate amongst themselves on a higher-level sensing task (e.g., reporting, with greater accuracy than possible with a single sensor, the exact speed, direction, size, and other characteristics of an approaching vehicle).

The sensors can be deployed in any facility or area which has to be sensed in three main types. It can either be 1) triangular sensor deployment, 2) square sensor deployment and 3) irregular sensor deployment. These deployments are depicted as follows:

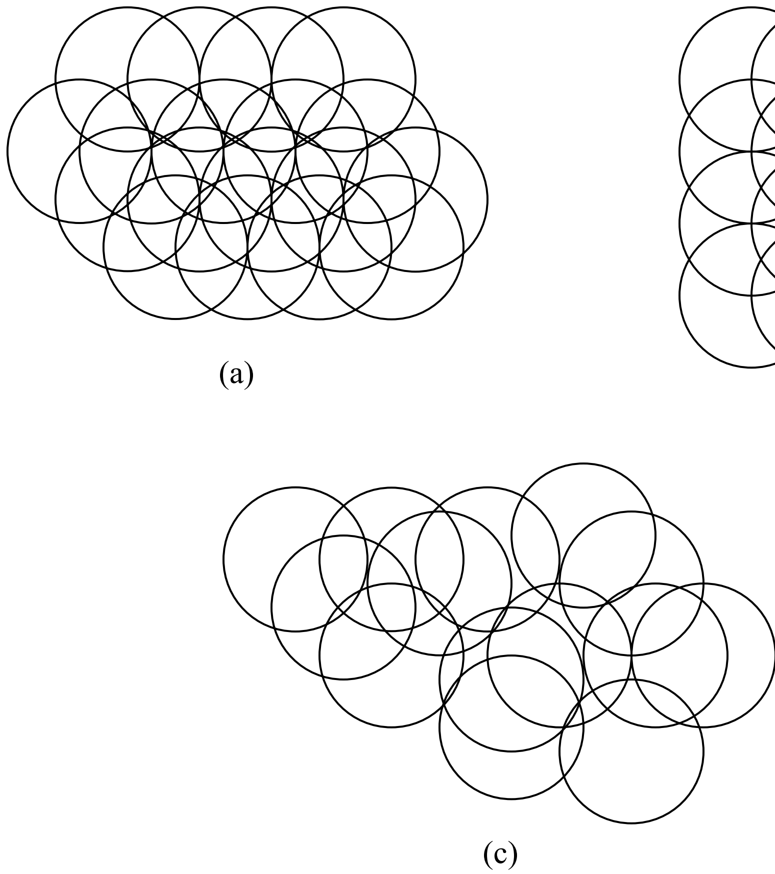


Figure1. (a) Triangular, (b) Square and (c) Irregular Networks

Networking inexpensive sensors can revolutionize information gathering in a variety of situations. Consider the following scenarios, arranged in increasing order of complexity:

-Stores such as Wal-Mart have started implementing RFID system in their warehouses. Right now, this pilot project is being implemented at their five major Super Center warehouses in Texas. All items from various manufacturers being stored in their inventory have a tag attached to them. Sensors discretely attached to walls or embedded in doors and ceilings, track the location history and use of items. The sensor network can automatically locate items, report on those needing servicing and report unexpected large-scale movements of items or significant changes in inventory levels. Some systems today (for example, those based on bar-codes) provide inventory tracking; full sensor-net based systems will eliminate manual scanning and provide more data than simply location.

-During a relief operation or at a disaster site, when the need is to know what the conditions are and we need to scan the area, sensors can be dropped from a helicopter over the area. They help to scan the area and construct the maps which are very helpful for first responders and assist them in performing their job. Right now, however the process is very human intensive.

-To plan a travel itinerary could become very simple when every vehicle in a large metropolis has one or more attached sensors. These sensors capable of detecting their location, traffic speed and densities, road conditions and so on could exchange information summaries such as which roads are highly congested and whether any alternate routes should be chosen. These summaries eventually diffuse across sections of the metropolis. We can also know about the driving conditions such as pollution levels and routes could be planned based on any social activities in the area as well.

For such futuristic scenarios, there remains a concern for such unattended sensors to operate and collaborate in the process of sensing, data collection and reporting. Also, the concern of their being in a hostile environment is always there. Following are some of these concerns explained in detail [10, 16]:

a) **Scalability:** A sensor network typically comprises of a large number of nodes spread randomly throughout the area. Managing all these becomes a very difficult task. The number of nodes depends on the application. Distributed and localized algorithms are essential in these cases. We can be mislead into thinking that increasing the number of sensors in an area leads to better tracking results, but this is not the case; since beyond a critical threshold increasing the number of sensors does not improve the location precision in tracking. Hence, the placement of the sensors in an area should be so as to maintain a balance between number of sensors and coverage required. Now, the density, $\mu$ can be calculated as

$$\mu(R) = (N.\ \pi.\ R^2)/A$$

where N is the number of scattered sensor nodes in region A and R is the radio transmission range. Here, $\mu(R)$ gives the number of nodes within the transmission radius of each node in region.

b) **Stability:** Since sensors are likely to be installed in outdoor or even hostile environments, their failure is an issue of concern always. The system must be able to operate well without supervision. This unattended mode of operation is common nowadays. In industry today, there are computer networks which operate without any supervision. In defense, we have Unmanned Aerial Vehicles (UAVs). This example illustrates an essential requirement of sensor networks: they operate and must respond to very dynamic environments. Sensor networks instead are deployed in a very ad hoc manner (e.g. thrown down at random from an aircraft). Nodes are damaged and fail due to limited power available with them. The networks have to be able to overcome node failures and be able to reconfigure themselves. Considering such scenarios in which typical sensor networks have to operate, in one of the solutions each sensor node is an Internet-capable device (has one or more IP addresses) and can run applications and services. When deployed, sensor nodes establish an ad hoc network amongst themselves; thereafter, different application instances running on each node can communicate with each other.

c) **Power:** Sensors are deployed in different terrains and since no source of power supply is available, sensor devices are operated by battery. Hence, energy conservation is a prime concern at all times. Operations such as on-board signal processing and communication with neighboring nodes consume a lot of energy. Thus, energy awareness has to be incorporated in every aspect of design and operation which means it is an integral part of groups of communicating sensor nodes and the entire network and not only in the individual nodes. Energy has to be conserved at the cost of performance in many cases since we do not require an extremely efficient solution to our problem.

A sensor node usually consists of four sub-systems [16] as shown in Fig.2:

a) A **computing** subsystem: In a sensor node, the microprocessor (microcontroller unit, MCU) is responsible for functions such as control of sensors and execution of communication protocols. Since these functions consume a lot of energy, an MCU operates under various modes of energy consumption.

b) A **communication** subsystem: This comprises of short range radios used to communicate with neighboring nodes and the outside world, these devices operate under the *Transmit*, *Receive*, *Idle* and *Sleep* modes having various levels of energy consumption. The maximum energy consumption is in the first two modes and if the sensor is not performing any function, it should be shut down rather than putting in *Idle* mode.

c) A **sensing** subsystem: Low power components can help to significantly reduce power consumption here since this subsystem (sensors and actuators) is responsible for the sharing of information between the sensor network and the outside world.

d) A **power** supply subsystem: Since a battery supplies power to the sensor node, the amount of power being drawn form it is constantly being monitored. The lifetime of a battery can be increased by tuning it on and off depending on the functionality of the node in question. This process should ideally be automated.

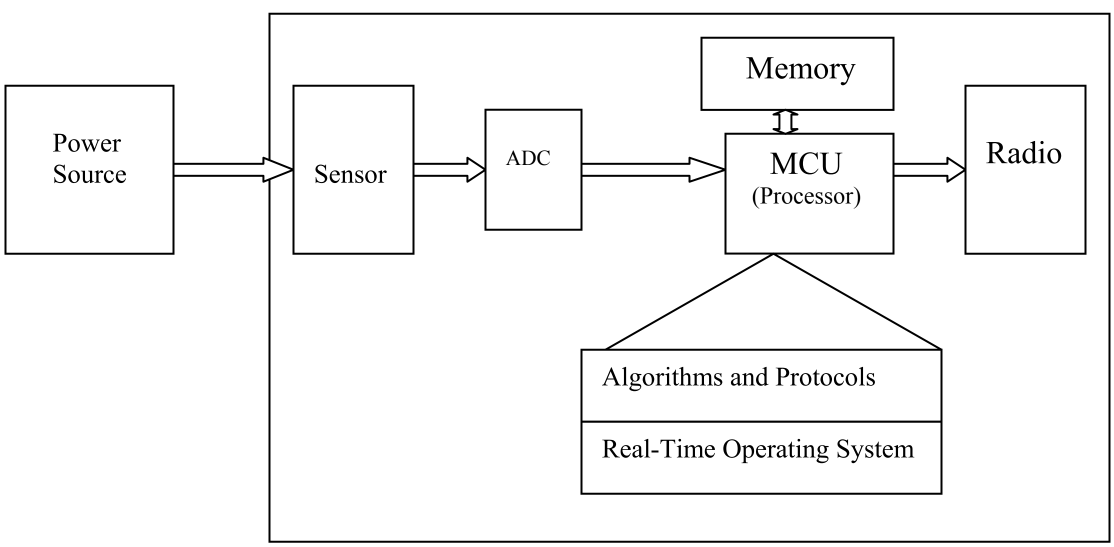


Figure2. System architecture of a wireless sensor node (Bharathidasan et al, 2003)

Since, sensor network requirements are different enough from those of traditional wired and wireless networks, it is important to consider a design having the following features:

a) **Data-Centric:** Unlike traditional networks, a sensor node may not need an identity (e.g., an address). Rather, applications focus on the data generated by the sensors. In some situations, for example, for querying a specific faulty sensor, the ability to address an individual sensor is clearly necessary. Data is named by attributes and applications request data matching certain attribute values. Most sensor data is associated with the physical context of the phenomena being sensed. Hence, spatial coordinates are a natural way to name data. This makes localization – determination of the position of the node in some coordinate system – an important problem.

b) **Application-Specific:** Sensor networks can be designed to perform a number of functions. Individual sensor nodes in a network can perform the functions of information gathering, collecting and storing and forwarding of information/data on request from neighboring nodes. This is in contrast to a centralized structure in the case of routers that facilitate node-to-node packet switching in traditional networks. Individual sensors report their data to a central node, which then performs the computation required for the application. This centralized structure is a bad choice for several reasons: it provides a single point of failure, it can be energy inefficient, and it doesn't scale to large networks. Thus, localized algorithms are better suited to sensor networks in which each sensor node communicates with neighboring nodes and computation is performed locally, yet the entire structure achieves a desired global objective. Since the sensors are physically distributed, it is not unnatural to design sensor networks using distributed algorithms. Furthermore, localized algorithms have two attractive properties. First, because each node communicates only with other nodes in some neighborhood, the communication overhead scales well with increase in network size. Second, for a similar reason these algorithms are robust to network partitions and node failures.

### 1.2 Routing [16]

Conventional routing protocols are not very energy efficient. In the case of sensor networks, the nodes have very limited energy and there is no external source of battery input power. Hence, care must be taken as to how the information routing takes place. It should be such that there is a fine balance between shortest path selection and energy used. Routing protocols are either proactive or reactive. In the former, updated routing information between all nodes is maintained in the routing tables. In the latter, the routes are created as and when they are needed. In any case, routing can be either forward based (source initiated) or backward based (destination initiated).

The simplest case of routing is ***flooding*** in which a node sends the information to all its neighboring nodes. However this scheme suffers from the following problems:

a) **Implosion:** If a node is a neighbor to nodes holding the same information, it will have duplicate copies of the same data resulting in a waste of resources.

b) **Resource Management:** In this scheme, the nodes are not resource-aware and perform their activities regardless of the available energy. This is highly undesirable in a sensor network scenario.

Some of the routing protocols which have been proposed in an effort to tackle the above mentioned problems are:

#### 1.2.1 Negotiation Based Protocols

These protocols are called SPIN (Sensor Protocols for Information via Negotiation) protocols. As the name suggests, there is negotiation prior to transfer of date between them. *Meta-data* are information descriptors here and used to eliminate the transmission of redundant data. In SPIN, track is kept of the energy level of the node. Prior to transmission, a node checks with it as to whether it has sufficient energy to carry out the transmission of data. The three main types of messages passed between nodes in this family of protocols are:

**ADV:** Whenever a node has some new data, it sends this message advertising to its neighbors. The message contains a meta-data as well.

**REQ:** Whenever a node wishes to receive some data, it sends out this message.

**DATA:** This message contains the actual data along with a meta-data header.

The following protocols constitute the SPIN family of protocols:

a) **SPIN-PP**: This is a point-to-point communication protocol. In this, energy is not a constraint. The data is transmitted by the source as many times as there are requesting nodes and hence is very energy inefficient. It is thus not ideal for a wireless sensor network scenario. Whenever a node has some data, it sends out an ADV message. The neighboring node checks the meta-data header to see whether it has the data already stored. If not, it sends out a REQ message requesting for the data item. Upon receiving this message, the originating node sends DATA message containing the data item. Thus, it is a 3-way handshake protocol. The advantage in this protocol is that a node needs to know only about its single hop neighbors.

b) **SPIN-EC**: This is also a 3-way handshake protocol but has energy constraints. A node participates in the protocol only if its energy level is greater than the energy threshold, i.e. it can complete all stages of the protocol.

c) **SPIN-BC**: This protocol is for broadcast networks. The nodes use a single shared channel for communication purposes. Whenever a node sends a message, all the nodes within a range receive that message. If the originating node receives a request it broadcasts the data item only once, even though it may have got multiple requests. If any other node receives an REQ message, it cancels that request so there are no redundant requests for the same data item. Also, whenever a node receives an ADV message it cannot immediately respond with an REQ message and has to wait for a certain time before doing so.

d) **SPIN-RL**: This is primarily an extension of the above protocol. In this, each node keeps track of all the advertisements it hears and the nodes it hears them from. If the node does not receive the requested data within a certain period of time, it sends out the request again. The originating nodes have a restriction on the frequency at which they can send the data messages.

### 1.2.2 Directed Diffusion

This is a data dissemination protocol which is destination initiated. This means that routes are set up whenever data is requested. Data generated by nodes is named by attribute-value pairs which basically describe the task. This description is called an interest. The data is requested by a node called sink and it requests by broadcasting its message periodically to all its neighboring nodes. The path setup between the destination and the originating node and data aggregation is based on interactions between the neighboring nodes.

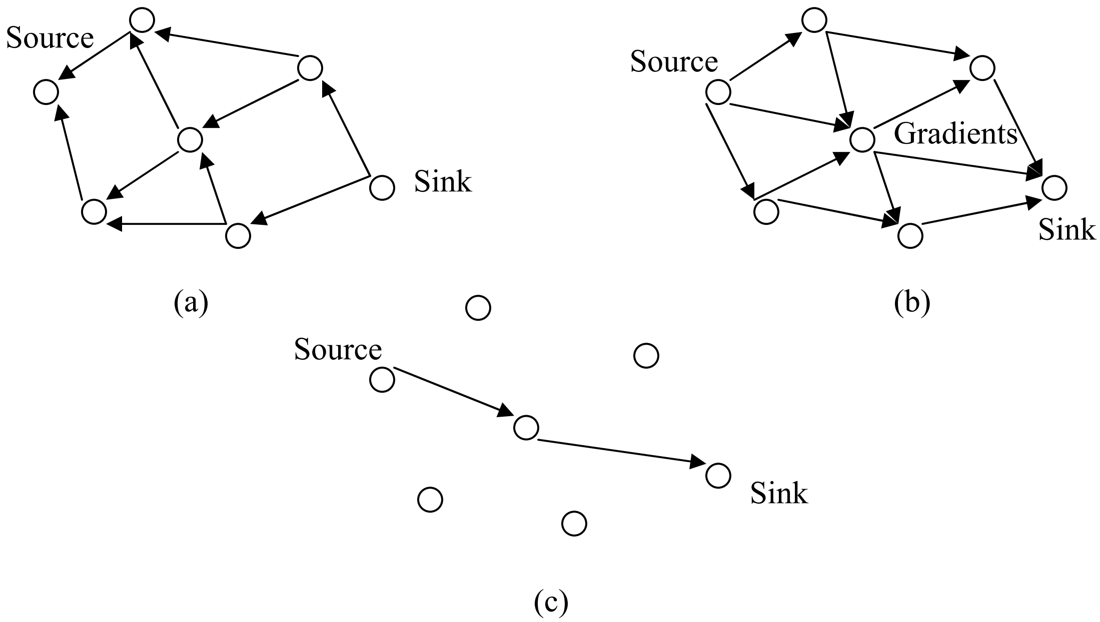


Figure3. a) Interest Propagation b) Gradients Setup
c) Reinforced Path for data delivery (Bharathidasan et al, 2003)

Fig. 3 illustrates the Directed Diffusion technique. When a node receives an interest it checks its interest cache to see if it has an entry. If not, it creates an entry and a gradient towards the node it received the interest from. The gradient is removed from its interest entry when the duration of the request expires. A node may also send the interest it receives to its neighbors, thus resulting in a diffusion of interests. The node which finds a match of the interest in its interest cache generates even data samples at the highest rate computed from all the requested event rates from its neighbors. The event description is sent along multiple paths and the sink receives the data from various sources out of which only one path is reinforced which is a better performing path.

**1.2.3 Energy Aware Routing**

This is similar to Directed Diffusion routing, the only difference being that instead of one optimal path, several optimal paths are maintained and chosen by means of a probability of the energy consumption of each path. No path is selected at all times and paths are switched. This leads to a gradual degradation of the network resources because energy is burnt more equally in all nodes of the network.

Initially, connection is initiated through localized flooding to discover all the routes. The resources and costs are computed and routing tables maintained. Data is forwarded from source to destination using the neighboring nodes in the forwarding table with the probability of the node being chosen being same as the node being chosen in the forwarding table. Localized flooding thus helps to keep the paths alive and active.

### 1.2.4 Rumor Routing

Queries are aimed to be routed to only those nodes which have observed an event. Thus, query is not flooded; rather it is generated and routed randomly across the network till it finds the event path. Agents create paths directed towards the events that occur. The aim is to maintain the most efficient path in the routing table. Any *agent* has a limited lifetime of a fixed number of hops. Each node contains a list of its neighboring nodes and an events table to which any new event which it notices is added. Subsequently, it generates an *agent* in a probabilistic fashion.

### 1.2.5 Multipath Routing

In this case, although the main path between source and destination is one, alternate paths are maintained which are only partially disjoint from the main path. These paths are called *braided multipaths*. As we expect, alternate paths are usually longer and energy inefficient and to maintain such paths is a drain on the network resources. In this case however, since the paths are only partially disjoint from the main path, they are quite comparable to it. These are so that if a node fails, there are alternate routes to the destination and make a network more resilient.

# 2. LITERATURE SURVEY

## 2.1 Target Tracking: The Problem

Since sensor networks are typically used to monitor the environment, one fundamental issue is the location-tracking problem, whose goal is to trace the roaming paths of moving objects/individuals in the area in which sensors are deployed. This problem is challenging in two senses: (1) there are no central control mechanisms and backbone network in such an environment and (2) the wireless communication is very limited. At present, location tracking is done using GPS. However, GPS has its limitations. It cannot be used in most indoor environments. It depends on Line of Sight. Also in non-urban outdoor settings, GPS does not yield accurate results because it depends too much on factors such as terrain, foliage and topographical settings of the place where the object is located. Since, GPS receivers may be too large, too expensive or too power intensive, using wireless sensor networks provides us with a better alternate for location tracking since the nodes are relatively small, inexpensive and low power devices. They are much more viable considering economic and convenience constraints.

Some other techniques [12] have also been proposed in the past as alternates to the trilateration technique. They are:

a) **Infrared:** RFID tags emit infrared radiations carrying a unique ID. This is received by a number of receivers scattered across a facility which resolve the location of the badge based on distance.
b) **Ultrasound:** These are also distance based systems but provide a better estimate by measuring time-of-flight of ultrasound with respect to a reference RF signal. MIT's Cricket system is an example of this.
c) **Radio:** The systems which utilize radio waves provide a better approximation for location detection because of the ability of these waves to penetrate various materials. Instead of using differences in arrival times as in Ultrasound, these systems utilize signal strength to measure the location.

The general tracking strategies in terms of deciding which nodes are activated for tracking purposes i.e. in terms of energy efficiency are:

a) **Naïve Activation (NA):** In such a tracking scheme all nodes are in tracking mode all the time. This strategy offers the worst energy efficiency. Since it offers the best tracking results, it is a useful baseline for comparison.
b) **Randomized Activation (RA):** In this strategy, each node is on with a certain probability *p.* On an average, a fraction p of all nodes will be on and in the tracking mode. It is a more energy efficient solution than NA.
c) **Selective Activation (SA):** In this activation technique, a few selected nodes in the network are selected at a time depending on their distance from the object. As and when the object moves, the distances also change from those nodes and thus, 'handovers' take place between nodes. It offers a good balance between energy efficiency and tracking precision.
d) **Duty-Cycled Activation (DA):** In this, the entire sensor network periodically turns on and off with a regular duty cycle. The major advantage of this scheme is that it be used in conjunction with the three techniques mentioned above. It is not the smartest of solutions in terms of energy efficiency but fares better than NA.

Below are listed some of the techniques proposed till now in an attempt to solve the Target Tracking problem:

1) The following technique has been proposed by Yu-Chee Tseng, Sheng-Po Kuo, Hung Wei Lee and Chi-Fu Huang at the Department of Computer Science and Information Engineering at National Chiao-Tung University, Taiwan [10]. The paper discusses the following technique:

Whenever an object is detected, based on the distances of the sensor nodes from the object, three closest nodes are selected to monitor the movements of the object. At any time, these sensors monitor the movements of the object. These three agents (master and slaves) will perform the trilateration algorithm and calculate the (x, y) coordinates of the object. The sensors tracking the object keep changing as the object moves. The election process is constantly done based on the location of the object at different time instants.

There is a certain signal strength threshold used to determine when to revoke/reassign a slave agent. The master may forward tracking histories to the location server.
The paper has discussed the above technique with some constraints on the movements of the object. The object is assumed to be moving at a constant speed of 1-3 m/s and the sensors are not able to detect the object if it moves at a speed of more than 5 m/s.

2) This technique has been proposed by Asis Nasipuri and Kai Li at the Department of Electrical and Computer Engineering at The University of North Carolina at Charlotte [3]. The technique is as follows:

Consider a network in which sensor nodes are scattered at random. These nodes track the object and relay the information to the Control Unit as and when required. For various operations such as signal processing, data transmission, information gathering and communications the sensor nodes have a memory, a processor and supporting hardware. The sensor nodes have limited transmission range. They rely on store and forward multi-hop packet transmission to communicate. Each beacon signal is an RF signal of a separate frequency on a narrow directional beam with a constant angular speed of ώ degrees/s. Thus, the transmissions are distinguishable. The sensor nodes determine their angular bearings with respect to these signals. The supposition in this case is that transmission range is sufficient for the beacon nodes to be received by all sensor nodes in the network.

In the paper, the authors have considered a rectangular network area at the corners of which are located the four beacon nodes. Consequently, each sensor node receives periodic bursts of the four beacon nodes with the same period of 360/ ώ seconds.
The localization principle is based on a sensor node noting the times it receives the different beacon signals and evaluating its angular bearings with respect to the beacon nodes by triangulation.

3) Data-centric and Location-centric approaches to the Target Tracking problem have been elaborated by R. R. Brooks, Sr. Research Associate, Applied Research Laboratory, Pennsylvania State University, P. Ramanathan and A. M. Sayeed,

Professor, Electrical and Computer Engineering Department, University of Wisconsin [6].

In the Data-centric approach, sensor nodes respond to particular requests. Whenever the nodes detect a request corresponding to the data they have, they transmit the data. Other nodes do not respond but take note for future use. Subscribed nodes receive data over the network.

Diffusion routing is one of the solutions proposed to route data in the data-centric approach. Interests of particular nodes are disseminated and gradients set up within the network helping to pass the relevant data to the interested nodes. Paths are then reinforced and data flow takes place only along these specified paths.

In the Location-centric approach, cells are created as per requests and tasked accordingly. The activities of the nodes in the cell are coordinated by a manager node. The occurrence of "events of interest" is collaboratively decided by all the nodes in the cell. If the object moves out of the current cell, the manager node has the responsibility of creating a new cell to track the object.

The authors illustrate a location-centric approach developed at the University of Washington. In this case, a Route Request (RREQ) is needed to forward data from cell to cell unlike the creation of paths in diffusion routing. The cells are addressed by their geographic locations. As the RREQ propagates, state information is temporarily deposited in the network to identify an efficient route from the source to the destination. On receiving the RREQ, the node in the addressed cell responds with Request Reply (RREP) which is routed to the destination cell resulting in a single path from source to destination cell along which data is sent to all nodes in the latter by the manager node.

4) The other technique for location tracking was proposed by Saikat Ray, Rachanee Ungrangsi, Francesco De Pallegrini, Ari Trachtenberg and David Starobinski at IEEE Infocom 2003 [12].

In this paper, the authors propose a location tracking methodology based on radio waves. These employ received signal strength to calculate the location of an object. Their technique basically speaks about selecting a set of points and then based on the RF-connectivity between these points; the transmitting sensors are placed only on a subset of these points. The sensors have a limited range of transmission and the observer would receive unique ID packets anywhere in this region. Since each point is served by a unique set of transmitters from which the location of the point can be known. Beyond the points incorporated into the graph model, this technique does not guarantee coverage. It has to rely on additional techniques for widespread coverage.

5) Yet another technique for location tracking keeping in view power considerations was put forward by Yi Zou and Krishnendu Chakrabarty at the IEEE Infocom 2003 [14].

In this paper, the authors talk about implementing a Virtual Force Algorithm for sensor deployment. This is based on the proximity threshold between two neighboring sensors. If the sensors are too close, they repel and if the distance between them falls below the threshold level, they attract. This leads to a uniform sensor deployment.

Once the sensors have been deployed, a cluster head is chosen which is responsible for implementing the algorithm. In order to minimize traffic and conserve energy, a notification is sent by a sensor to the cluster-head whenever the object is tracked which then queries a subset of sensors to gather more detailed target information. These are intelligent queries based on the cluster-head generating a probability table for each grid point and then subsequent localization if a target is detected by one or more sensors.

# 3. RESEARCH BASIS AND WORK PERFORMED

## 3.1 Research Basis

Yu-Chee Tseng, Sheng-Po Kuo, Hung-Wei Lee and Chi-Fu Huang [10], have developed a Location Tracking Protocol in which the tracking is done by the coordination of sensors. A network of sensors in a 2D plane is considered. A triangular network is considered i.e. the sensors are placed in a triangular fashion. Typically, the network is considered as a hexagonal mesh. Each sensor is aware of its physical location and that of its neighboring sensors. All the sensors have a processor, a memory and required hardware to support sensing, information gathering and communication capabilities. Each sensor has a sensing radius, r which is equal to the length of the side of the triangle. Three sensors are used to determine the location of the object. The methodology used in this case is the triangulation technique of detecting the spatial coordinates. The sensors in this case are assumed to have different sensing radii. The work presented aims to track the moving path of an object in the network. The sensors have an overlapping region of sensing which is known as the 'working area' and the areas surrounding these are known as 'backup areas' which imply that as soon as the object moves into these areas a 'handover' should take place.

As soon as a movement is detected, an *election* process is conducted among the sensors based on their distance from the object. The sensor closest to the object is chosen as the *master agent* while the next two are chosen as *slave agents*. As soon as the election process is done, all the other sensors are prohibited from tracking the object by sending them blocking messages. Using the trilateration technique, these sensors calculate the position of the object. From time to time the slave agents report their results to the master and the tracking histories are recorded. They are reported by the master as and when required. To reduce the amount of overhead, a master may choose to pass on the gathered information to the location server from time to time. A master agent can revoke and reassign a slave based on the movement of the object. Certain signal strength thresholds govern this. Also, incase the object moves out of the sensing area of the master agent, there is a provision for a reelection process and selection of a new master agent. The above process can be understood by Fig.3 in which till the time the object moves in the working area ($A_0$), the elected nodes do the sensing, while as soon as the object moves to the backup areas defines ($A_1$, $A_2$ and $A_3$), the sensor node farthest from the object is revoked since the signal strength falls below the threshold level.

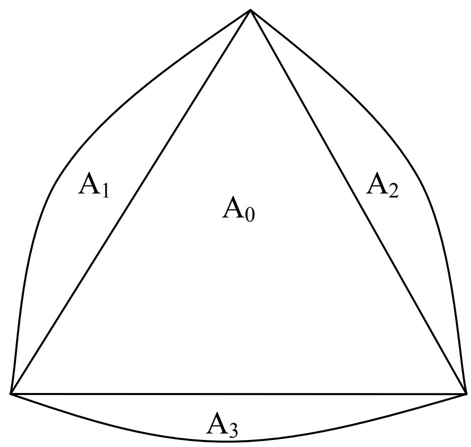


Figure4. Working area and backup areas

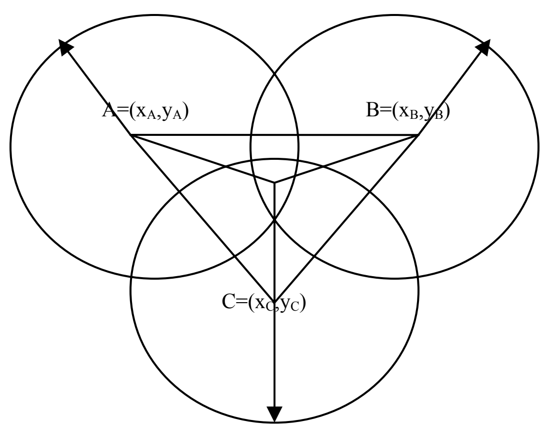


Figure5. Position Approximation Algorithm (Tseng et al, 2003)

It has been assumed that the sensors can distinguish objects which may be due to the unique ID transmitted by the objects. Thus, the environment considers multiple objects although the technique has been depicted for one object. Sensors usually have four modes of operation: *Transmit Receive*, *Idle* and *Sleep* based on the operation they are performing. Each of the nodes has a different level of power consumption. Initially, all the sensors operate in the *Idle* mode of operation in which they continuously detect any object within their sensing scope.

The variance of signal strength with distance is measured and smoothed out using a regression quadratic polynomial. Signal strengths can vary and the measurements are not very accurate. Thus, there are always some errors between estimated distances and actual distances. The trilateration technique used basically uses the intersection of three circles to find out the exact spatial coordinates of the object. In a real world scenario, the three circles never intersect at a common point. Hence, to minimize error, an approximation algorithm has been used in which the difference function is minimized. The difference function, $\sigma_{x,y}$ is calculated as

$$\sigma_{x,y} = \left|\sqrt{(x-x_A)^2+(y-y_A)^2}-r_A\right| + \left|\sqrt{(x-x_B)^2+(y-y_B)^2}-r_B\right| + \left|\sqrt{(x-x_C)^2+(y-y_C)^2}-r_C\right|$$

where A, B and C are the sensor nodes and $(x_A, y_A)$, $(x_B, y_B)$ and $(x_C, y_C)$ are their center coordinates and $r_A$, $r_B$ and $r_C$ are the distances to A, B and C from any point $(x,y)$ on the plane. In the experiment, location of the object is measured every one second.

### 3.1.1 Extension to Four Sensors

The above trilateration technique has also been used to do target tracking with four sensors. However in this case, the sensor positions are changed from being the vertices of an equilateral triangle in a hexagonal mesh to being arranged in a square position. The tracking is done by these four sensors simultaneously at an interval of one second. The tracking results however do not show any significant improvement over the results with three sensors.

### 3.1.2 Assumptions

1) Sensors can distinguish between multiple objects
2) A hexagonal mesh network

3) Consider only grid points on the plane
4) Object does not move faster than 5m/s
5) Object moves at a constant speed of uniform distribution between 1~3m/s
6) No obstacles in the area
7) Due to signal strength variation with distance, the algorithm has an inherent 5% error in tracking, i.e. during approximation; it considers points in the range ($x \pm 5$, $y \pm 5$).

### 3.1.3 Limitations

1) The trilateration technique which has been proposed shows good tracking results. However, the detection capabilities of the system are limited. It cannot track objects traveling at speeds of more than 5m/s which is a huge limitation in terms of tracking of mobile objects. This means that if between t=0 and t=1 time instant, the object moves at a faster speed then the tracking plot would show a straight line between t=0 and t=2 time instant, the latter being the next detection time. Thus, the object's movements at t=1 sec remain unknown. In other words, zero displacement movements are not tracked.
2) The detection is done only at one second intervals. Thus, the sudden deviations in the object movement which occur between these remain undetected. This in turn a serious limitation when we talk in context of fast moving objects.
3) When four sensors are used, they are deployed in a square position. This is not in accordance with the normal arrangement of the sensors, i.e. a hexagonal mesh. This can be cumbersome and can have lot of overheads.

## 3.2 Research Work Performed

The work performed is theoretical in nature. The technique has not been implemented on the ground, yet the attempt is to establish a technique which is simple and robust and can improve the tracking results considerably for very special conditions of velocity and acceleration which is not being done by the technique described above.

The work described in the following paragraphs is an extension of the work described above. The technique has been developed with four sensors. It utilizes the fourth sensor in a totally different fashion than the other three sensors; the fourth sensor employs an estimation technique for those time instants when the other three don't track the object. This technique is very simple and quite accurate in nature. The efficiency of tracking has also been improved by increasing the detection frequency of the network. Velocity has not been considered as a constraint and the object has been allowed to accelerate.

### 3.2.1 System Model

We consider a hexagonal mesh constituting a triangular network of sensor nodes. Object is tracked only inside this network.

As soon as an object movement is detected, the four closest sensors to it are identified; their node numbers recorded, spatial coordinates generated and distances from the object calculated using the distance formula. The object is tracked using the three closest sensors. These sensors calculate the spatial coordinates of the object using the trilateration technique described above. In this technique, all points in the vicinity ($x \pm 5$, $y \pm 5$) are considered resulting in an inherent 5% error. This has been done to take into account the signal strength deterioration with distance which is shown below [10].

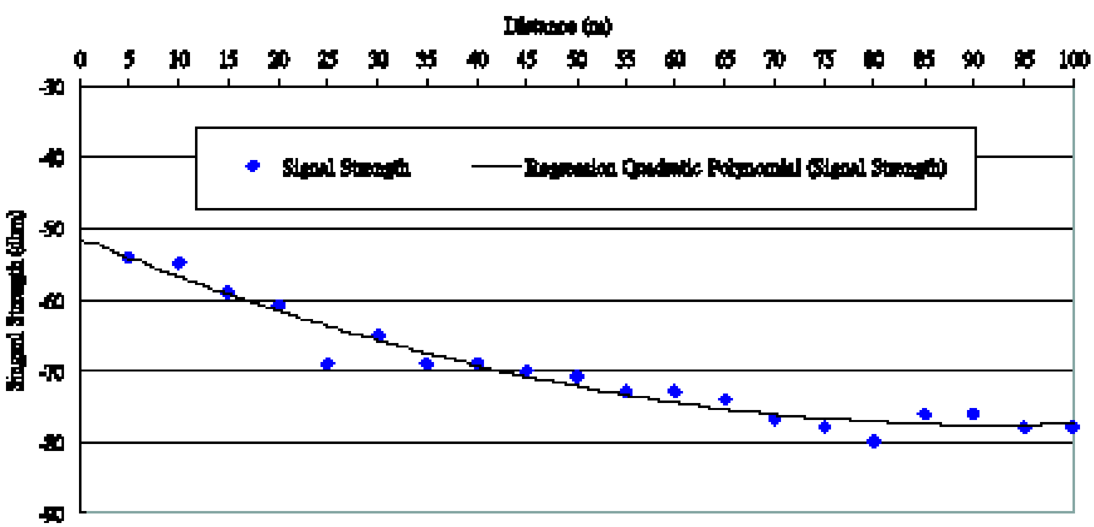


Figure6. Signal Strength Vs Distance (Tseng et al, 2003)

The point whose distance from all three sensors is the least is considered is taken as the estimate location of the object. These sensors measure the object location at every one second interval.

The present technique employs the trilateration technique for estimating the location of the object with three sensors at the end of every one second. It also employs the same approximation algorithm as before in which the difference function is minimized. The difference function, $\sigma_{x,y}$ is calculated as

$$\sigma_{x,y} = \left|\sqrt{(x-x_A)^2+(y-y_A)^2}-r_A\right| + \left|\sqrt{(x-x_B)^2+(y-y_B)^2}-r_B\right| + \left|\sqrt{(x-x_C)^2+(y-y_C)^2}-r_C\right|$$

where A, B and C are the sensor nodes and $(x_A, y_A)$, $(x_B, y_B)$ and $(x_C, y_C)$ are their center coordinates and $r_A$, $r_B$ and $r_C$ are the distances to A, B and C from any point $(x,y)$ on the plane.

It goes beyond by employing a fourth sensor which works at twice the frequency, i.e. it detects the object at every half second. Now at the time instants when the detection is being done by three sensors, i.e. at every one second interval, even the fourth sensor is calculating the distance to the object. However, its distances are not taken into account, while at half second intervals only the fourth sensor is tracking. It estimates the location of the object as *d*. This *d* is the same value as its distance estimate of the object at the beginning or end of that second depending on which one is greater. Now knowing the object location at ½ sec prior to and after the current location as well as knowing the estimate *d*, the angles subtended by these two points at the fourth sensor are calculated. Since the estimate *d* is known, the position of the object at that ½ sec interval is estimated as follows:

$$X_{est} = d * \cos(\Theta) \quad \text{and} \quad Y_{est} = d * \sin(\Theta)$$

where calculation of Θ has been explained in detail below.

The problem also arises when the object deviates from its path at a half second interval near the edge of a cell. This results in two different sensor nodes being selected as the fourth sensor, one for the object location ½ sec before and one for the object location ½ sec after. Thus, the system does not know which fourth sensor's distance estimate to consider while determining the location of the object. This deadlock is again broken by choosing the fourth sensor having the greater distance from the respective points. This helps to minimize the error as having a larger distance reduces Θ and thereby Θ/2.

#### 3.2.1.1 Calculation of Θ

The two angles Θ1 and Θ2 subtended at the fourth sensor by the two points are calculated. Since $\tan^{-1}$ is positive between (– Π/2, Π/2), the angles are transformed to this range and hence we consider only the first and fourth quadrants. For our convenience in calculation, the scale is changed from (– Π/2, Π/2) to (0, 2Π). Now Θ is optimized by the following technique:

$$\Theta = min\ (\Theta 1, \Theta 2) + (max\ (\Theta 1, \Theta 2) - min\ (\Theta 1, \Theta 2))/2$$

After this, the estimation formula which has been discussed earlier is used.

The accuracy of the location estimates is characterized by a variable called '*Error*' in which *Error* is defined as

$$Error = \sqrt{(X_{est} - X_a)^2 + (Y_{est} - Y_a)^2}$$

where $X_{est}$ and $Y_{est}$ are the estimated locations of the object by applying the algorithm and $X_a$ and $Y_a$ are the actual positions of the object in the spatial coordinates.

### 3.2.2 Assumptions

1) Sensors can distinguish between multiple objects.
2) A hexagonal mesh network.
3) Consider only grid points on the plane.
4) The sensors are assumed to be omni directional having the same tracking radii, *r*.
5) Velocity is no longer a constraint.
6) Object accelerates.
7) No obstacles in the area.

8) Object does not make big variations in direction from its path, i.e. it cannot make jumps greater than one half the side length of the cell. Also, it cannot switch cells in this process. It remains inside the cell at all times.

The other two special scenarios that have been tackled are:

1) Displacement of the object in one second is zero and we want to know the location of the object at t=½ sec irrespective of the velocity of the object. This has been tested for one second intervals when either all three sensors are active or when only the fourth sensor is tracking the object.
2) Movement of the object is circular within a cell or within number of cells.

### 3.2.3 Advantages over Previous Work

1) Much more versatile algorithm in terms of detection capabilities. In addition, the estimation technique with fourth sensor is very simple, straightforward and accurate.
2) The technique developed allows detection of objects at speeds greater than 5m/sec. In fact, good tracking results have been shown for movements up to 30~33m/sec. These are specifically good for fast moving objects such as individuals who are mobile.
3) The detection capability of the system has been improved. Although, detection is being done at every second, it is used to estimate the position of the object at every half second interval with the help of the fourth sensor. Thus, mobile objects which can make sudden deviations within a one second interval are also tracked.
4) Special cases such as zero displacement and circular movements have been tackled as well.
5) Although four sensors are being used, the hexagonal mesh environment is not disturbed and the deployed sensors remain in the same locations throughout their lifetime. Thus, overhead costs are also avoided.

# 4. TRACKING RESULTS AND ERROR PLOTS

The tracking results and error plots shown in the following pages have been obtained after simulating in Matlab, the technique proposed in the previous chapter. Straight line, zero displacement, circular and random motion tracking results for speeds up to 30~33m/sec have been shown. These illustrate the capabilities of the technique, its robustness and suitability to the various situations encountered in the real world. Referring to the system model described above, using the trilateration technique for detection and the estimation technique for the fourth sensor, these results have been obtained which lie within the acceptable error limits ~ -5% to +5%.

The variations in the results are due to the deterioration of signal strength with distance. This has been taken into account and thus, an inherent $\pm 5\%$ error in selection of points has been built into the algorithm. In addition to this, the wide fluctuations found in the error plots at some places where the fourth sensor is active and being used for estimating the position of the object is where the object is usually changing cells or at the border of a particular cell. At these places, two different fourth sensors get activated based on the location of the object at the beginning and end of the time instant and hence, the estimation is not as accurate as in the case where only one fourth sensor would have been selected for location estimation.

In the tracking plots, some nodes are shown yellow and some are shown as darkened circles. The former indicate that those sensor nodes have only been selected as one of the three closest sensors during the motion of the object i.e. these sensor nodes have only been used for detection. The darkened circles indicate that those sensor nodes have been selected for both detection and estimation purposes, i.e. even as a fourth sensor.

In the subsequent pages, first tracking results and error plots for circular motions followed by straight line motion have been shown. Then graphs have been shown for straight line and zero displacement motions, the latter being done for both even and odd time instants. After this, random motion of the object in the +y and –y direction has been tackled for both even and odd time instants and results shown.

Fig.7 is a tracking plot showing the tracking result of an object moving in a circular motion. The center of the circle is (6, 0) and the radius is 1. The colored circles indicate the sensor nodes which are selected as three closest nodes. The darkened circle indicates the fourth sensor node for a particular object location.

Fig.8 shows the error in tracking the above circular motion of the object. The error ranges from +6% to -4% for the y-axis. The mean error for the above case is less than +.5% and the median is also close to it. The standard deviation in this case is close to 2%.

Fig.9 tracking plot shows the tracking result of an object moving in a circular motion. The center of the circle is (7, -1) and the radius is 2. The colored circles indicate the sensor nodes which are selected as three closest nodes. The darkened circles indicate the fourth sensor nodes for particular object locations. Some of these sensor nodes have been selected as one of the three closest sensor nodes for a previous object location.

Fig.10 error plot shows the error in tracking the above circular motion of the object. The error ranges from +5% to -5% for the y-axis. The mean error for the above case is less than -5% and the median is close to it. The standard deviation in this case is also close to 2%.

Fig.11 tracking plot shows the tracking result of an object moving in a straight line. The x-coordinates change in this case while there is no change in the y direction.

Fig.12 error plot shows the error in tracking a straight line movement of the object. The error in this case ranges from +2% to -4%. The standard deviation ranges is close to 2%. The mean is close to 0 and so is the median. The results in the above figure are shown for a deviation of 16.66 m for every ½ sec, i.e. more than 33 m/sec.

Fig.13 tracking plot shows the tracking results for an object deviating from the straight line path at the 9$^{th}$ time instant. At this instant, only the fourth sensor is active and the tracking plot shows the precision with which the movement has been tracked.

Fig. 14 error plot shows the error in this case to be ranging from +2.5% to -4%. The standard deviation is about 2.5% while the mean is close to 0. The median is about -0.5%. At the 9$^{th}$ time instant, the error is within the standard deviation range indicating good tracking results with the fourth sensor. The results are shown for a deviation of 16.66 m for every ½ sec, i.e. more than 33 m/sec.

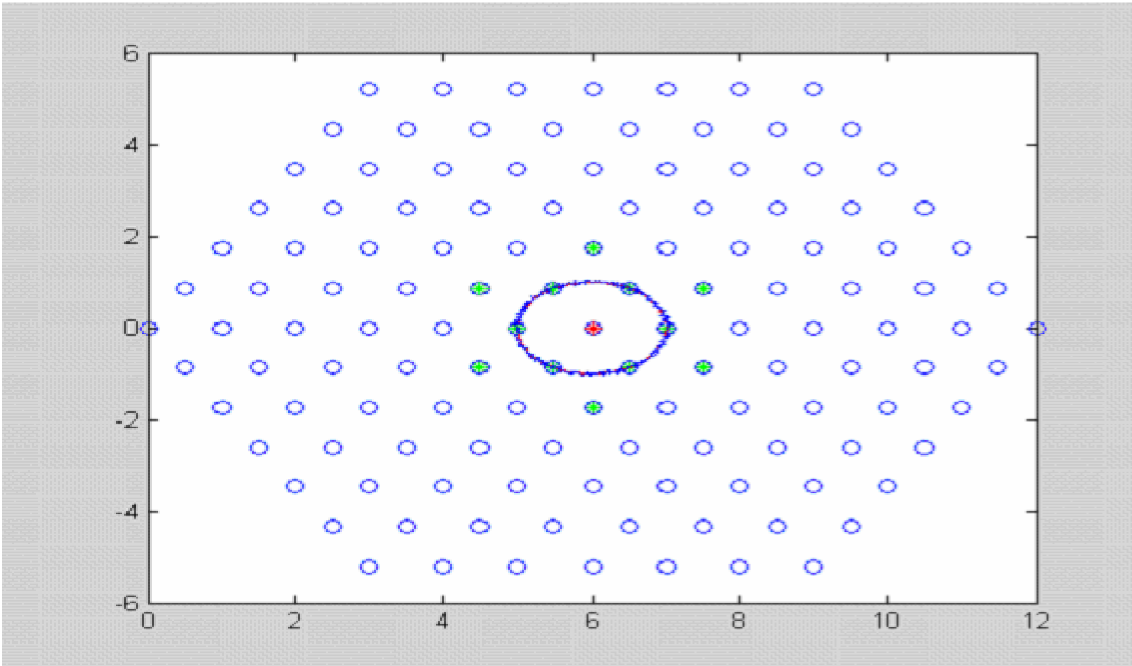


Figure7. Tracking circular motion with center (6, 0) and radius 1

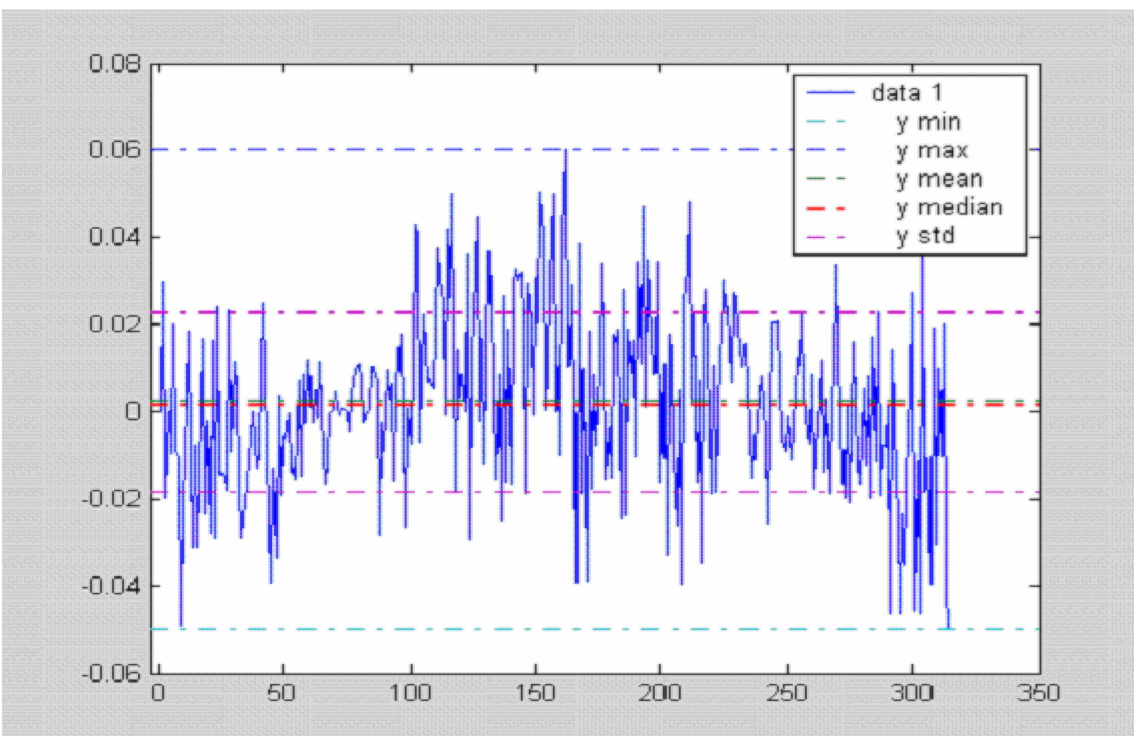


Figure8. Error Vs Point Plot

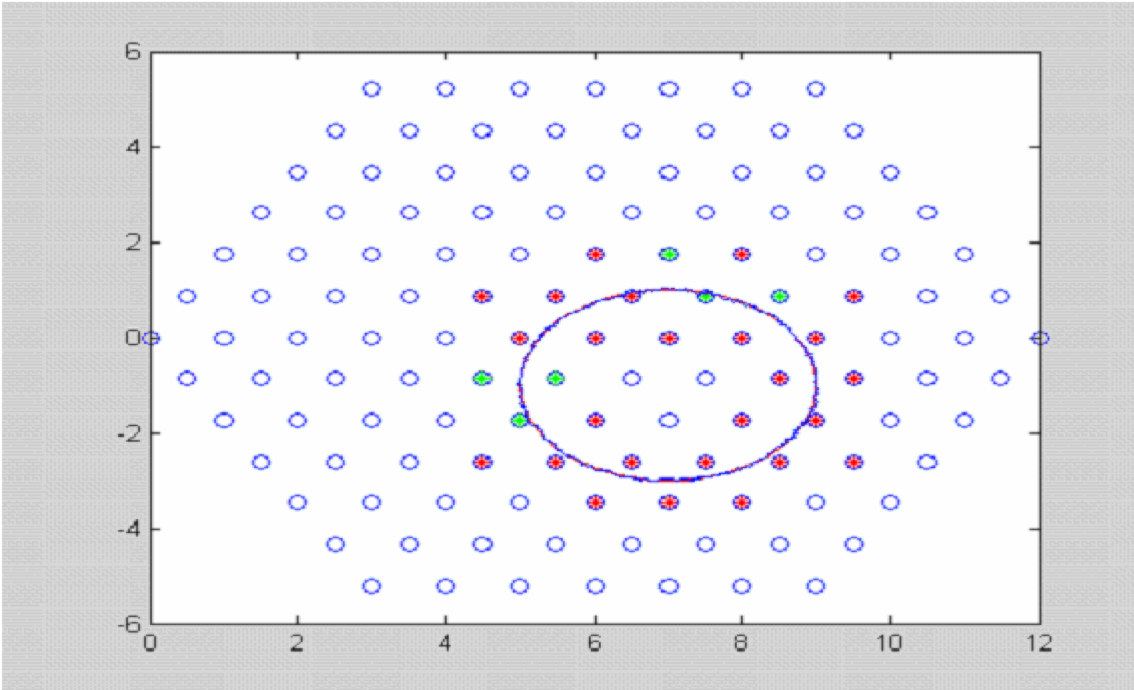


Figure9. Tracking circular motion with center (7,-1) and radius 2

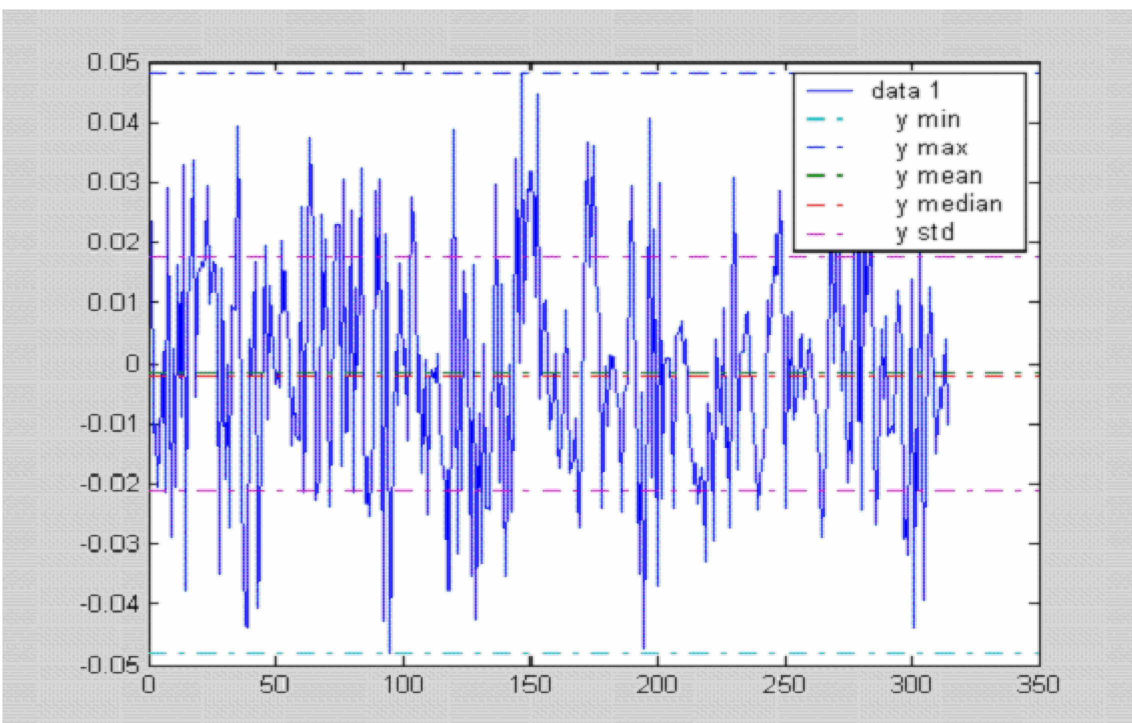


Figure10. Error Vs Point Plot

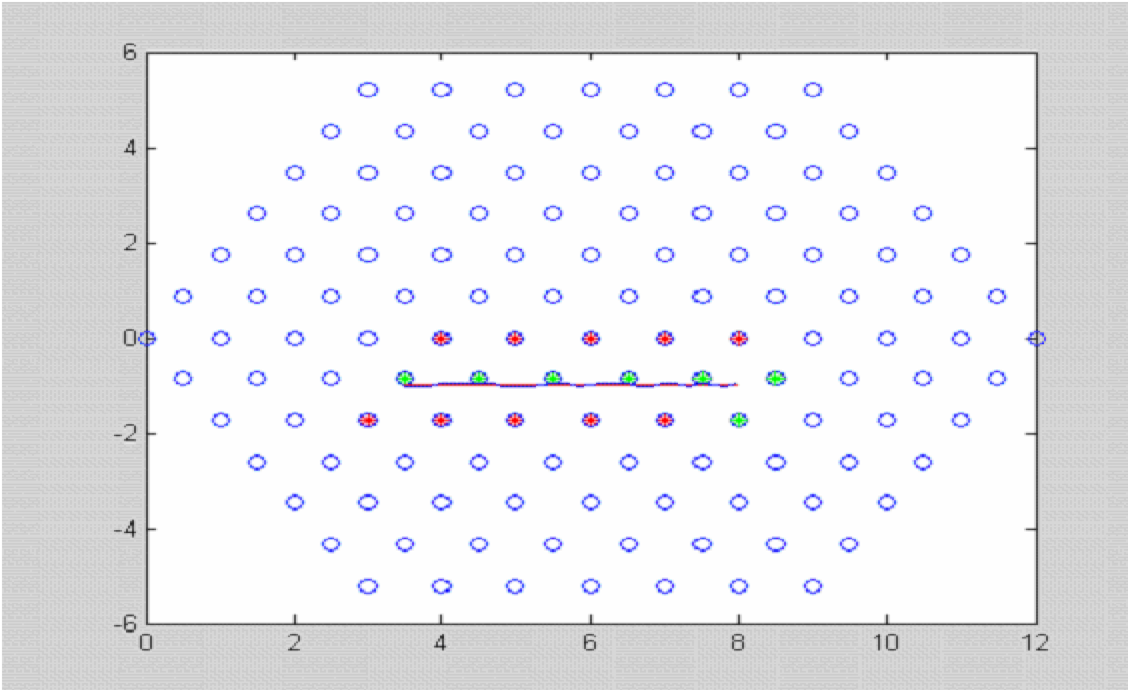


Figure11. Straight line Plot

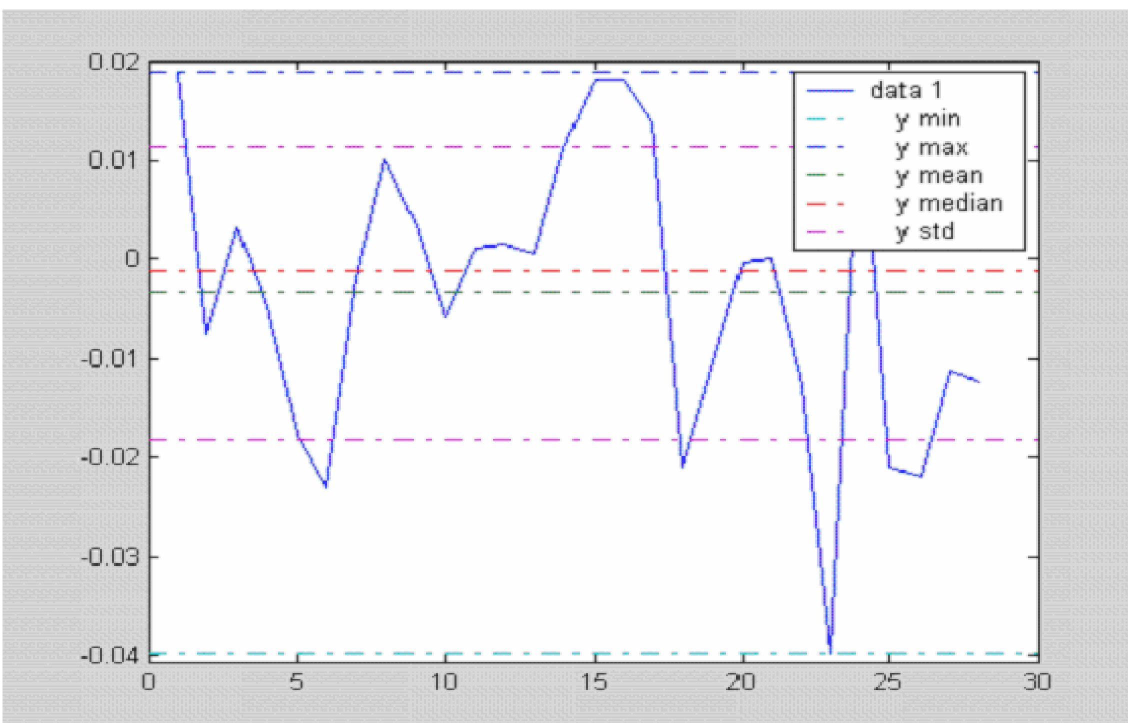


Figure12. Error Vs Point Plot

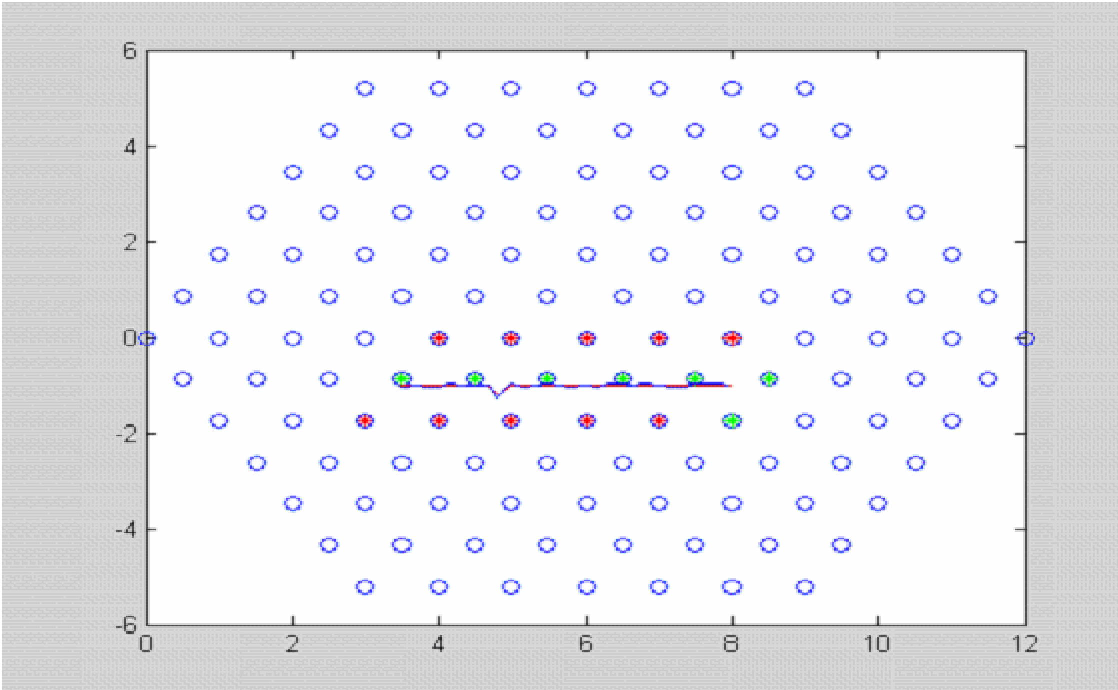


Figure13. Straight line Plot with deviation at 9th time instant

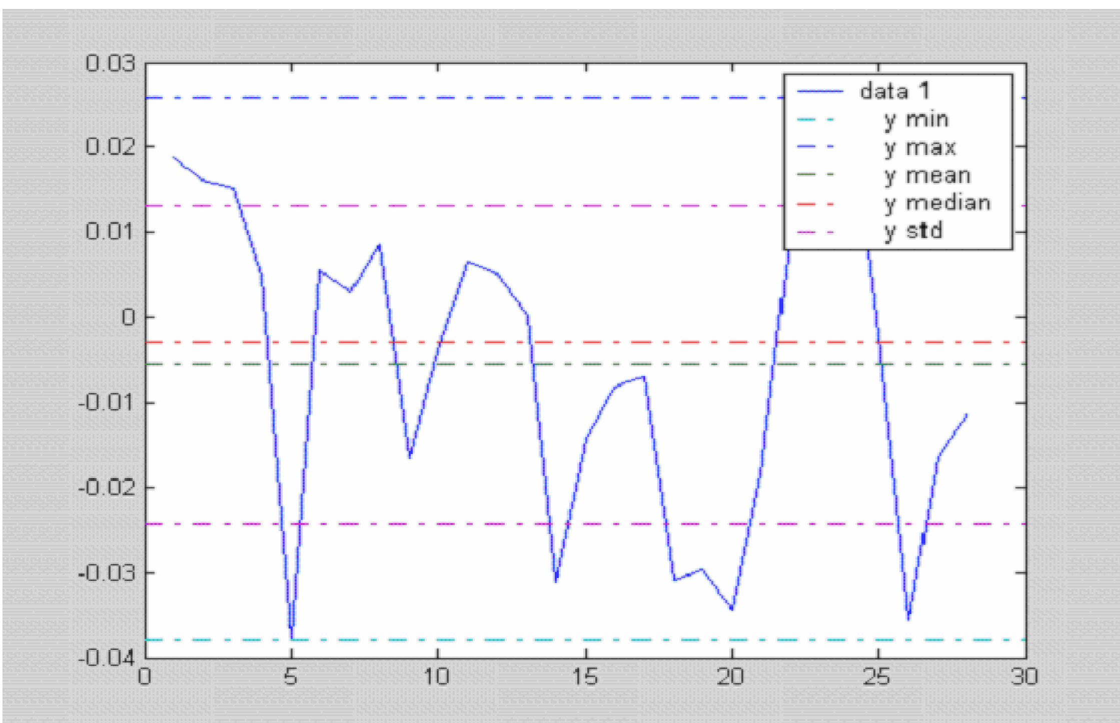


Figure14. Error Vs Point Plot

Fig.15 tracking plot shows the tracking of an object moving in a straight line with zero displacement between 6th and 8th time instants, i.e. during one second time interval. At these time instants, the three closest sensors track the object.

Fig.16 error plot shows the range of error is from +4% to -12%. The standard deviation is about 4%. The mean and median are both close to 0. At the 6th and 8th time instants, the tracking error is within the standard deviation range. The results are shown for a deviation of 16.66 m for every ½ sec, i.e. more than 33 m/sec.

Fig.17 tracking plot shows the tracking results for an object moving in a straight line with zero displacement between 15th and 17th time instants, i.e. in one second interval. At both these time seconds, only the fourth sensor is tracking the object.

Fig.18 error plot shows the error ranging from +7% to -4% with only one point having a substantial error. The standard deviation is about 5%. The mean and median are both about 2-3%. The results are shown for a deviation of 16.66 m for every ½ sec, i.e. more than 33 m/sec.

Fig.19 tracking plot shows the tracking result for the object movement at both even and odd time instants, i.e. at time instants when all three sensors are active and when only the fourth sensor is active. All the sensor nodes which are selected in the process are shown.

Fig.20 error plot shows the maximum error as +15% and minimum as -15%. The standard deviation is about 5% and the mean and median are very close to 0. These indicate good tracking results for both even and odd time instants. The results are shown for a deviation of 15.38 m for every ½ sec, i.e. more than 30 m/sec.

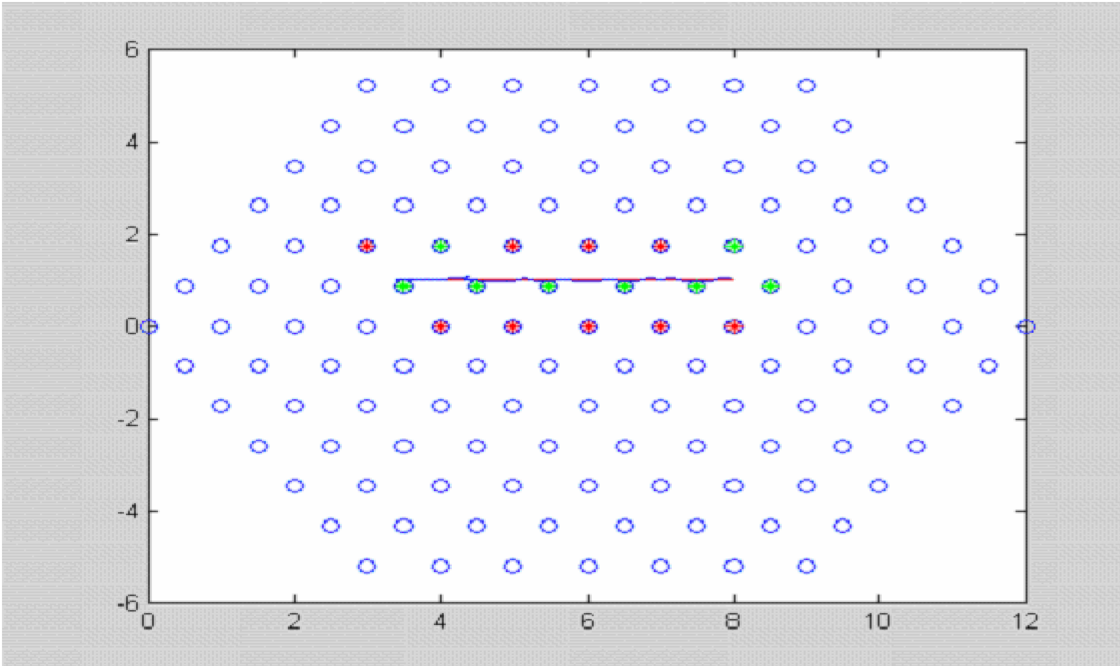


Figure15. Straight line Plot with zero displacement between $6^{th}$ and $8^{th}$ time instants

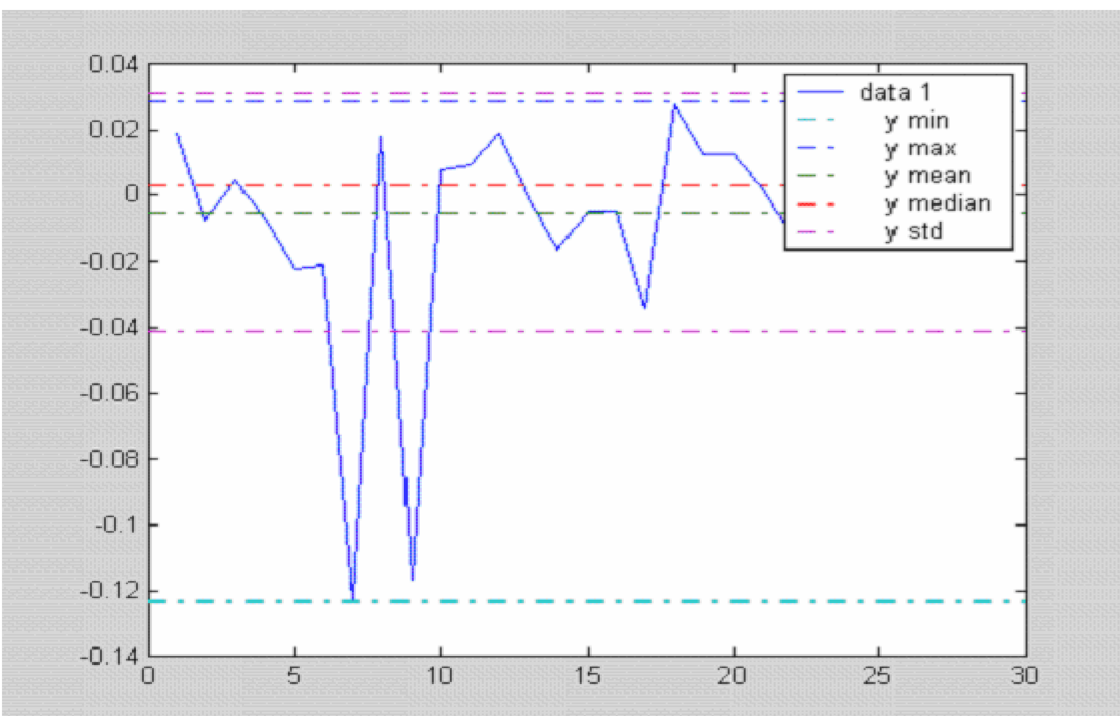


Figure16. Error Vs Point Plot

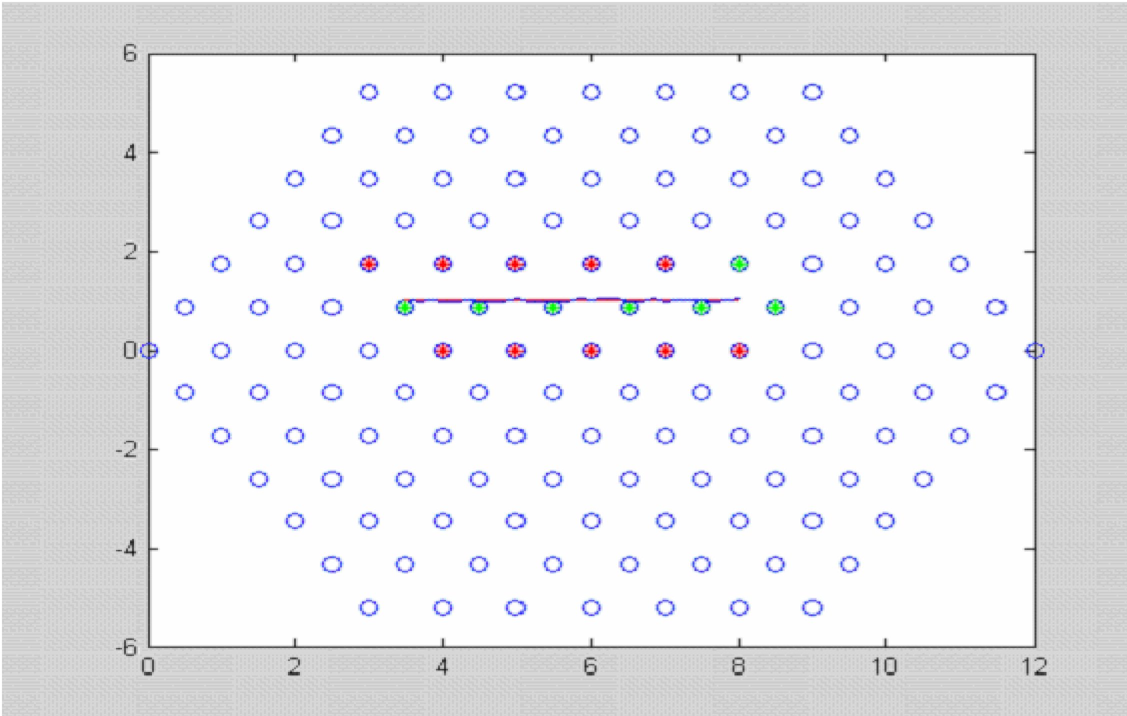


Figure17. Straight line Plot with zero displacement between 15th and 17th time instants

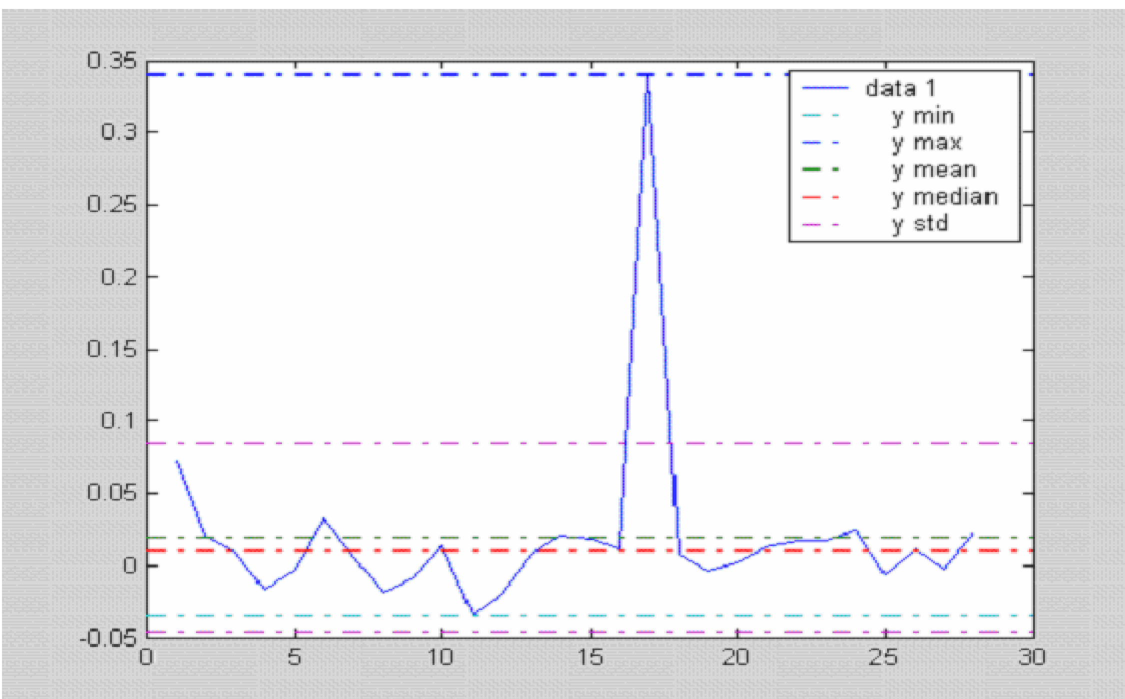


Figure18. Error Vs Point Plot

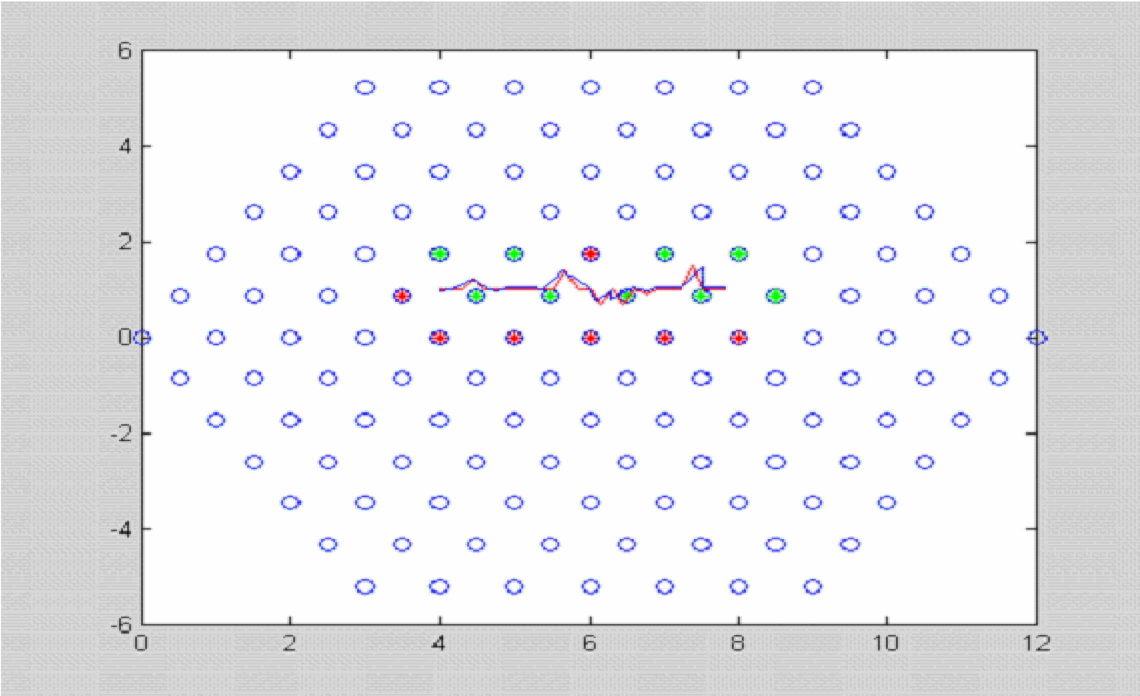


Figure19. Straight line plot with deviations at even and odd time instants in the +y and –y direction

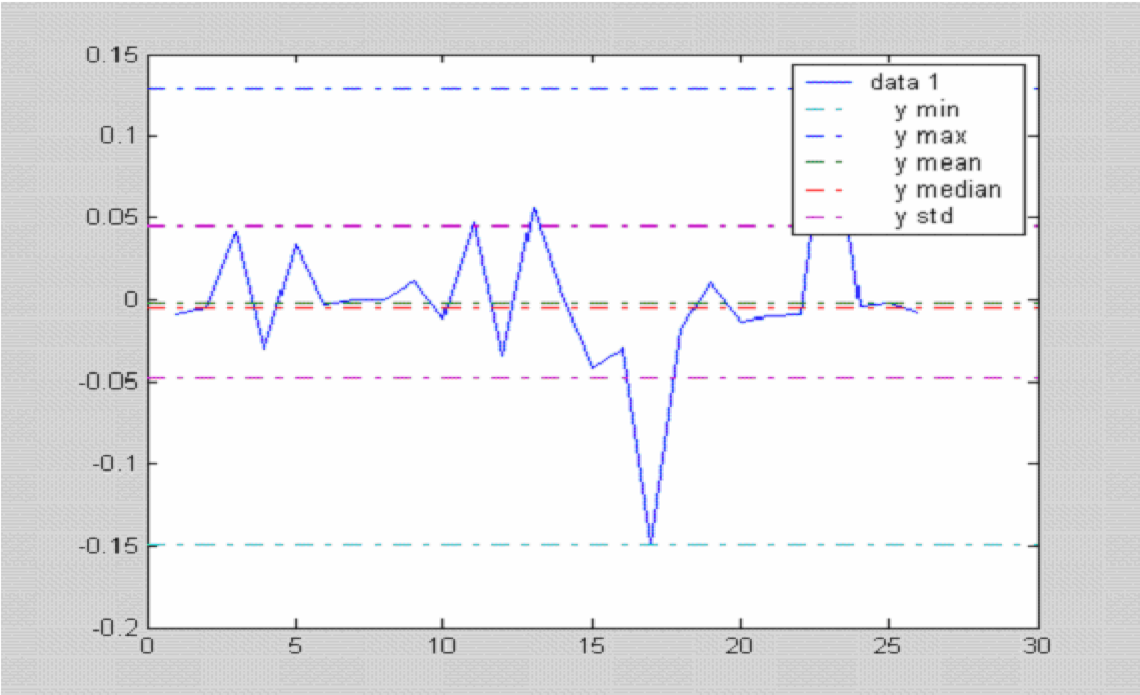


Figure20. Error Vs Point Plot

## 5. APPLICATIONS OF THE WORK PERFORMED

Applications of target tracking and/or data fusion are found in diverse civilian and military fields. Civilian applications include air traffic control, navigation, fault tolerant systems and decision problems. In the military field, applications include surveillance, target identification, command and control, sensor management and weapon guidance.

The target tracking problem is widely researched due to its increasing applications in security industry due to heightened concerns about the safety of men and material in present day world. In order to keep a check on movements of suspicious people and their activities, we have to employ video monitoring and surveillance and tracking systems. Tracking is useful in keeping check on movements of individuals whether pedestrians or mobile in heavily congested areas such as business district of cities, government buildings, nuclear facilities, borders, seaports, airports and national monuments. We have to be able to do this in an efficient manner optimizing utilization of all our resources and must look at low cost techniques of doing so. Tracking basically assists the first responders in taking immediate corrective actions such as deny and destroy of individuals who may pose a threat. While tracking, a couple of things have to be kept in mind such as 1) what objects need to be tracked 2) what is the setting, i.e. urban or rural 3) what are the capabilities of the system i.e. how accurately does the system track and 4) what are the acceptable levels of tracking.

The work which has been performed helps to address the issues raised earlier. It employs a simple and effective technique to track objects. This technique is efficient and the errors associated with the tracking results are very acceptable in nature. Such a tracking system can be deployed to keep a check on movements of individuals in business districts or can be used in conjunction with video surveillance systems for safeguarding government buildings, monuments, airports, seaports and borders.

The system is able to track objects moving at low and high speeds which are typical in a city environment. By being able to track objects moving as fast as up to 33m/s within acceptable error bounds, it can very well adjust to a scenario where the need is to track fast moving targets. This usually can be thought of as a typical scenario at a city center where we have pedestrians as well as vehicles and which is a likely place of attack.

As mentioned earlier, such a tracking system can be used along with a video surveillance and monitoring system. A typical scenario could be near a nuclear facility. Say for example, a man is walking and he intentionally drops a bag. Immediately, the cameras installed spot this abnormal activity and the object is tagged as well as the person. After this, the individual has to be tracked and his movements have to be kept under close watch. If the person tries to escape or if he goes out of the sensing range, the first responders have to be alerted to take the necessary action.

The technique which has been proposed also takes zero displacements into account. This scenario is common in city centers and important buildings and sites where an individual could plant an explosive or possibly a tracking device. If that individual makes a suspicious movement and then returns to his original location, since even half second movements are being tracked, the technique offers a good support to the video monitoring system in monitoring the building and its vicinity. Thus, not only are his motions detected but also tracked within that split second.

Circular motions have also been tracked using this technique. Such motions are common such as individuals are found to be studying a building plan or site. Such an observation usually spells trouble or is a point of concern. Such activities when noticed on a surveillance camera should be taken seriously and movements of such individuals should be tracked. This system enables one to do it quite effectively. In fact, the tracking results are highly accurate in this case.

The various scenarios which have been explained are some of the most common and likely. Such activities evoke suspicion and must be kept a check on.  The tracking and surveillance systems should be capable enough to track movements of any kind- straight, circular, random or fast. The technique developed tackles all of these with a high accuracy and also offers a cost effective solution since sensors are relatively very inexpensive when compared to systems such as GPS systems which make use of satellites.

Such a tracking scheme can be deployed to study the behavioral pattern of animals and the effect of various emotions on their movements. Animals are left in open fields and sensors deployed all over the area. The track followed by an animal can be tracked to know about its movements when it is sad, happy or excited. Such data is quite helpful to zoologists to conclude for certain that emotions are an integral part of not only human beings but also animals. Since they cannot speak, their actions and movements definitely tell us about their emotional well being.

In addition to this, such a study also helps the aviation industry. They can get information on bird activity in the closer vicinity of airports and hence are able to accordingly schedule arrival and departure times of various flights as well as decide the path to take and the flying altitude.

## 6. FUTURE WORK

The work performed has some limitations. The technique developed is theoretical in nature and has to be implemented on ground. Although the technique is shown to perform well at speeds of up to 33 m/s, it has to be tested to verify its performance on ground. The speed limit in this case can be adjusted according to what the error constraints are.

The main improvement in the algorithm can be brought about by removing the constraint on deviation of the object. In the current algorithm, the object is allowed to deviate up to 50% of the side of the cell in a particular direction. This is in order to keep the errors low. The algorithm may not perform well when deviation is greater than this or when deviation is from one cell to another. This is primarily because of selection of various sensor nodes as fourth sensors during this movement of the object. Thus, selection of a right fourth sensor to track the object is the challenge.

To actually replicate an urban setting, obstacles should be considered. Thus, reflections and absorption of signals from objects, buildings, people and vehicles should be considered and hence the effect of these on the signal strength. This could also have an effect on the accuracy of tracking results.

Another improvement in the tracking results could be brought about by employing all the four sensors for detection purposes. Although the technique is more power consuming, yet the results will be more accurate. One suggestion is to use trilateration taking three out of four sensors each time and finding the mean of the these points. The x and y coordinates can thus be estimated as

$$X_{est} = (X_1+X_2+\dots\dots\dots+X_k)/k \text{ and } Y_{est} = (Y_1+Y_2+\dots\dots\dots\dots\dots+Y_k)/k$$

where $X_1$ , $X_2$ ……$X_k$ and $Y_1$, $Y_2$ ........$Y_k$ are the positions estimated by applying the algorithm and $X_{est}$ and $Y_{est}$ are the final approximated positions by taking their mean. The other improvement could be made if we consider that different sensor nodes have different sensing radii. In this case, all sensor nodes have been considered to have the same sensing radii which may not be the case. It can be extended in this regard.

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## VITA

Tarun Anand Malik was born in Delhi, India, on December 5, 1981. He belongs to a military background. His father retired as a Brigadier General from the Indian Army and his mother was a teacher.

Tarun got his Bachelor of Engineering degree in computer science and engineering from Apeejay College of Engineering, Sohna (District Gurgaon), India affiliated to Maharshi Dayanand University, Rohtak, India, in 2003. He secured an honors degree in his under graduation.

He will receive his Master of Science in Electrical Engineering degree from Louisiana State University, Baton Rouge, Louisiana, United States of America, in 2005. His major area of concentration was communications/systems. He will graduate with an honors degree. His master thesis work was in sensor networks. The problem tackled was target tracking.

His interests are primarily in the telecommunications field. During his under graduation studies, he interned with Siemens, Hutchison and Avaya. He worked in both wireless (GSM, GPRS and UMTS) and wireline areas. He also studied intelligent networks and various switching and transmission techniques such as ATM, Frame Relay and SS7. He also developed an Agent Application Programmable Interface for Avaya Predictive Dialing System for call center agents in Visual Basic.

He has also worked in the security industry. During his master's studies, he interned with GTSI Corp. based in Virginia which was a part of Homeland Security Initiative. He worked on integration of physical security with data network. He covered various physical security edge technologies – video surveillance and monitoring, biometrics, detection of weapons of mass destruction, smart cards and RFID.

His interests primarily include sports, traveling, reading and music. He played squash at the National Level and badminton and basketball at the District Level in India.