POLITECNICO DI MILANO
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Final Thesis for M.Sc. Computer Engineering

SMART RESCUE System

for safety and security of Red Cross Crews based localization

using RSSI and IMU in Wireless Sensor Networks

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SMART RESCUE System for safety and security of Red Cross Crews Based Localization Using RSSI and IMU in Wireless Sensor Networks

A Thesis
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Abstract in English

A SMART RESCUE system is an aggregation of nodes which mutually launch a network to improve the performance of Red Cross Crews or workers by introducing a new Safety and Security Systems that would reduce the risk of Red Cross Crews' Life. In this network every node has processing capacity and RFID transceiver with power supply. For ensuring the security by using the status of the Personal Protective Equipment (Helmets, Shoes and Jackets), firstly I need to find crews' position or location in working environment. I demonstrate a new method for perfectly position or location estimation method. I have considered Received Signal Strength (RSS) received from various dynamic RFID tag packet which amalgamated with Inertial Measurement Units (IMUs). For this reason, the goal of this thesis work is to inclusion of the process and measurement model of the inertial sensor on board an ambulance or supplied to the rescue workers. For better accuracy and precision various stages implicated with that procedure which combine the Receive Signal Strength Indication (RSSI) and Inertial sensor measurements information. My methodology is reasonable for any sort of motion of crew's such as forward or backward movement at dissimilar speeds. For estimating the position and condition of a crews' I used inertial measuring units. Furthermore the solution of my approximated estimation problem has excellent properties in that with the increase of sensors are distributed by a plane, devoting no possibility to influence the exact location of every node. I measured the entire system experimentally by using autonomous tracking system where data are collected from different environmental situations.

Keywords:

Localization system, Received Signal Strength Indication, Safety and Security, Inertial measurement unit.

Abstract in Italian

Un sistema RESCUE SMART è una aggregazione di nodi che lanciano reciprocamente una rete per migliorare le prestazioni degli equipaggi della Croce Rossa o di lavoratori con l'introduzione di nuovi sistemi di sicurezza e protezione che consentano di ridurre il rischio di vita della Croce Rossa Crews . In questa rete ogni nodo ha capacità e ricetrasmettitore RFID con alimentazione elaborazione . Per garantire la sicurezza , utilizzando lo stato di protezione individuale (caschi , scarpe e giacche) , in primo luogo ho bisogno di trovare la posizione o luogo equipaggi in ambiente di lavoro . Dimostro un nuovo metodo per perfettamente la posizione o metodo di stima posizione. Ho considerato Received Signal Strength (RSS) ricevuti da varie dinamico RFID tag pacchetto che amalgamato con unità di misura inerziale (IMUs) . Per questo motivo , l'obiettivo di questa tesi è quello di inclusione del modello di processo e di misurazione del sensore inerziale a bordo un'ambulanza o fornita ai soccorritori . Per una migliore accuratezza e precisione varie fasi implicate con quella procedura che combinano le informazioni di ricezione Signal Strength Indication (RSSI), e le misure del sensore inerziale . La mia metodologia è ragionevole per qualsiasi tipo di movimento dell'equipaggio di come il movimento in avanti o all'indietro a velocità diverse. Per stimare la posizione e la condizione di un equipaggio ' ho usato unità di misura inerziali . Inoltre, la soluzione del mio problema di stima approssimata ha proprietà eccellenti in quanto con l'aumento dei sensori sono distribuiti da un aereo , dedicando alcuna possibilità di influenzare la posizione esatta di ogni nodo. Ho misurato l'intero sistema sperimentale utilizzando un sistema di tracciamento autonomo, in cui i dati sono raccolti da situazioni ambientali diverse .

Acknowledgment

I would like to thank my admirable advisor ***Prof. Roberto Negrini*** deeply, for his valuable and helpful advice, support and encouragements during this project. Special thanks to admirable co-advisor ***Prof. Andrea Pini*** for his useful and important advice and guidance at the beginning of the project. In addition I would like thank to all professors and staff of *Politecnico di Milano University*, especially *Como Campus*, for all their admirable and worthy work and dedication.

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Chapter 1: Smart Rescue System for Safety and Security.

1.1: Introduction

Security and safety has always been of key concern to every individual or an organization. During the last decade advances in wireless communications several methodologies have led to availability of many off the shelf products, enabled the growth of low-power, low-cost along with multiple functional sensors that are small sizes and can communicate across short distances. An intelligent system is therefore required which should not only detect but also preempt such hazards.

SMART RESCUE has been designed as a system of control of the material used during and emergency by improving the efficiency of staff, being able to focus on emergencies, will operate with greater efficiency and safety. Furthermore, the collection and processing of majority data at a centralized location incurs substantial latencies, reinforcing the geographical scope within which acceptable real-time response is possible. SMART RESCUE has been proposed for a large range of applications, such as defense area, emergency rescue workers, smart offices and so on.

The equipment available to the service personal in emergency relief in increasingly sophisticated, allowing the answer too many situations and many different issues. However, this increase in devices makes emergency management more complex and potentially greater risks resulting from human error. Consequently SMART RESCUE integrates the Personal Protective Equipment (Helmets, Boots or Jackets); an electronic identification system combining the comfort is the proper use and the geo-location of the rescuer, making it a very useful tool in the management of emergencies.

1.2: Goals and Objectives

Geo-Localization is the problem of determining the status of the rescuer in the system with verification of the correct functionality of the Personal Protective Equipment (PPE). Geo-Localization is one of the most profound problems that must be solved. The aim of this thesis is to monitor the status of all crews along with capable to handle any kind of rescue situations in an area, and provide warnings to crews or rescuer when they are approaching to take part in an action. These systems assist in avoiding collisions during the operations.

One of the objectives of this dissertation is to find the position of a mobile object or Personal Protective Equipment (Helmet, Shoe and Jacket etc.) which is equipped with an Inertial Measurement Units (IMU). It contained several accelerometers, gyroscopes, magnetometers and also pressure sensors. It has also calculated the force and angular velocity, which can be exploited to assistance navigation when the GPS signal is gravely attenuated. Its size and performance is linearly dependent. Such kinds of low-size and weight units which are based on Micro-Electro-Mechanical (MEMS) sensors are becoming most popular now a days [40].

Since, the Personal Protective Equipment which is equipped also with a microcontroller that iteratively sends RSSI information iteratively over 870 MHz channel. Some other nodes used for receiving signals from object and convey to server over the master node. Since the network is based on three-tier manner where root node is the server, majorly performs the localization, Master is the node which controls the Sensor Nodes, and it can estimate the perfect location of crews.

The goal of this thesis to describe the process model and measurement model of the inertial sensors (i.e. accelerometer and gyroscope) on board an ambulance or supplied to the rescue workers. For more accuracy and precision various steps involve with that procedure, which fuses the RSSI optimization and inertial sensor measurements. In place of using very few sample RSSI which receive by a sensor, here uses fixed number of sample size to optimize its value. On the other hand the distance between moving object and sensor can be measured by Log Normal Path Loss Model [10, 11 and 12].

This comprehensive work is comprised with some features which are as following: (Furthermore all these modules will be prefaced in detail)

The SMART RESCUE system allows a constant geo-location by an operations center of both the rescue means that the operating personnel. It allows a more accurate overview by the operations center, which could take prompt action to manage complex situations, achieves the goal of making a pro-active monitoring of personnel and equipment deployed in the field (or available in the theater of action).

Each rescuer is then clearly identified and the signal is raised to the operating center thanks to a control unit (Communication Gateway) installed on the rescue vehicle. The controller then has the function of connection, location and transmission.

SMART RESCUE provides the Localization via GPS (Global Positioning System) mean while receiving data from BAN (Body Area Network) through electrical devices on board an ambulance or supplied to the rescue workers.

- ***Technical clothing***
  The figure shows some of Personal Protective Equipment (PPE) provided to the supervision service. The goal is to combine the high technological level relative to the garments in use (technical features, comfort) the use of electronic technologies to improve the safety and effectiveness of the interventions of the operators. Particularly in the protective equipment in use at a number of sensors are integrated CRI Monitor System V1.4 able to check that the devices are actually wearing.

Figure 1: Technical clothing (Helmet, Shoe and Jacket)

- ***Central Control System***
  It's consists of a software application accessible via web with full support of men, equipment, events, scenarios, emergency response procedures etc. including geographic interfaces with geo-referencing capabilities.
- ***Software drivers and firmware***
  Analyze the states and the transmission of data on the location of the ambulance to verify the state of wear for Personal Protective Equipment (PPE).Also analyzed for geo referencing.

- ***Bridge*** (Gateway communication)
  To installs into the ambulance with connecting functions and localization, transmission.

- ***BAN(Body Area Network)***
  Small A central connection and recognition of type "card"
  A "Node Shoe" with sensors for state management of wear and future functions pedometer and distance traveled.
  A "Node Helmet" present only when required, equipped with central transceiver, sensors (accelerometers and temperature sensors) for the management of the states of wear.
  A "Node Jacket" equipped with central transceiver, sensors (accelerometers and temperature sensors) for the management of the states of wear.

- ***Moving Object***

It's equipped with small microcontrollers which iteratively send RSSI information through 868 MHz channel, has to be localized.

- ***Sensors***

Sensors are localized in a different position within a specific environment and the position of the sensor node is known. It's used to obtain the signals from the moving object and calculate RSSI. It will send to the server through the master after measuring RSSI.

- ***Master***

Master is places in one position and it is connected with the main RS485 Bus and server using RS-232 serial communication. Master is used to maintain the network by broadcasting different data packet across the RS485 data bus and also build a connection to the each sensor to receive its message.

- ***Server***

Its Windows Form application developed by Microsoft Visual Studio-2008 framework and used language is .net. It has one communication layer which involves establishing connection across the server and the master. The Server performs localization algorithm, measure the distance of moving object from each received sensors.

✓ ***Network Topology***

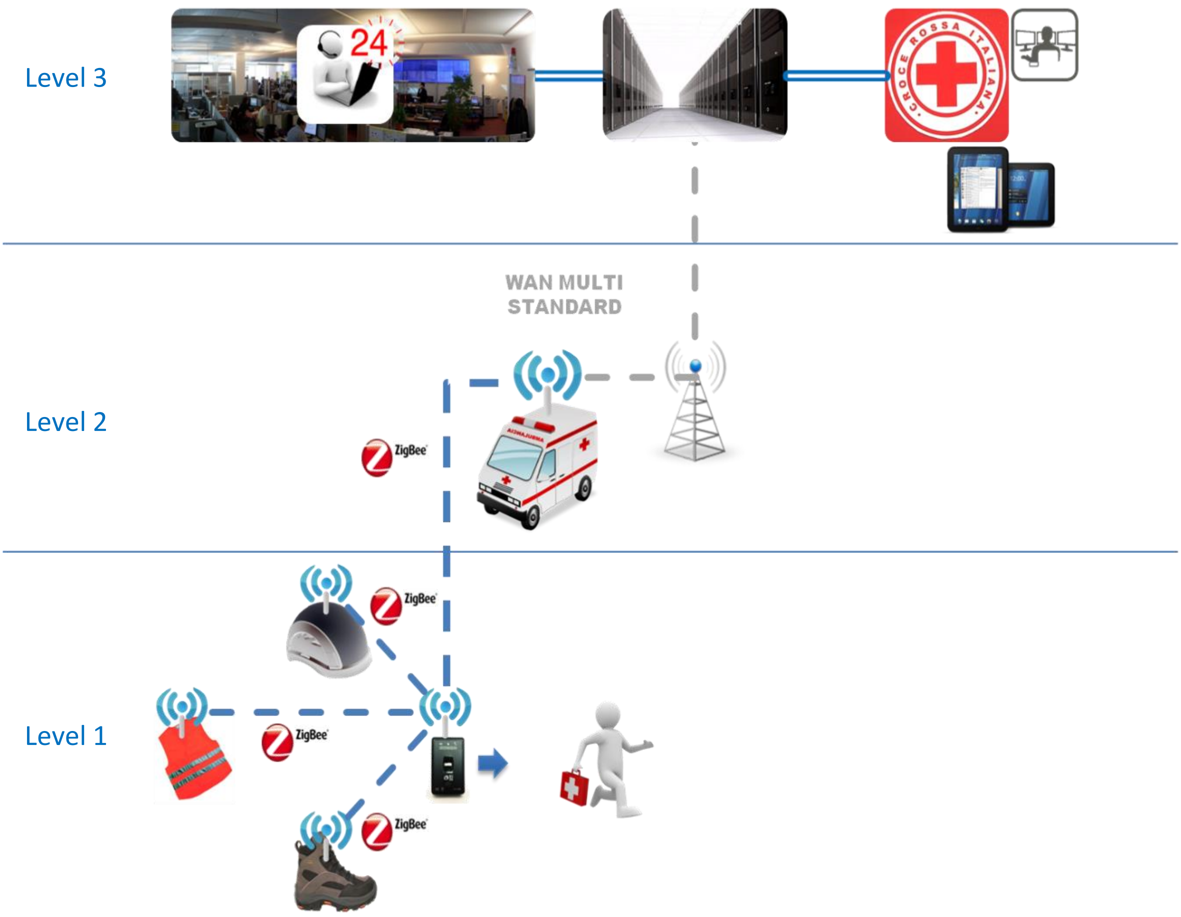


Figure 2: Schematic diagram of SMART RESCUE

1.3: Thesis Contribution

The thesis contribution can be summarized as follows: In next chapters has brief explanation on all of them.

- ✓ To provide a paradigm in which sensors and controllers can be progressively incorporated and programmed to autonomously coordinate with peer sensors. Hierarchies of controllers to detect notify and react to anomalous events.

- ✓ Considering the difference microcontroller and transceiver and choosing the suitable package for implementing the system
- ✓ Discovery and considering the various algorithms and methods, by defining the best one and most suitable system for implementing it.
- ✓ Implementing the Hardware and firmware of each section of the system and define theirs instructions
- ✓ Defining an improved procedure of the localization based on RSSI
- ✓ Implementing the software of server side for geo referencing procedure
- ✓ Performing outdoor and indoor tests to finding the efficiency and minimizing error of the system under different kinds of environments

In general the main goal of the project, I have tried to carry out proactive monitoring of personnel and equipment is suitable and accurate for localization in field of wireless sensor network or not? Moreover, under consideration the effects of changing with motion and temperature etc. I have tried to find the accuracy of the system.

1.5 : Comprehensive Overview of Thesis Book.

I have mentioned earlier wish to propose the problem and my thesis contribution to monitor the status of rescue workers according to power of its signals which is received by some sensors. The remaining of my thesis work organized as follows:

- ✓ Chapter 2: is an introduction about Wireless Sensor Network localization methods.
- ✓ Chapter 3: Explanation on the Received Signal Strength Indicator (RSSI) and IMU.
- ✓ Chapter 4: is about the background and related works in this area.
- ✓ Chapter 5: is for presenting the localization procedure and brief definition of each component of the system.
- ✓ Chapter 6: is about hardware implementation and the algorithm of firmware for each component has been presented.
- ✓ Chapter 7: is the measurement and result of the system.
- ✓ Chapter 8: is application of the system. Usefulness of this system.
- ✓ Chapter 9: Conclusion and Future Recommendation based on this thesis.

Chapter 2: Wireless Sensor Network Localization Methods

2.1: Introduction

The estimation of position or location of any object is derived as Localization. Feasibility can vary because of some troubles for the comportment of different factors. Gradually the research area in wireless sensor networks is getting more significant and interesting. It's becoming very easier to get low cost/power and multi-functional sensors which are portable and able to intercommunicate across short distances. The wireless communication offer well prospects for controlling and supervising different kinds of application such as tracking system, Military arena and safety and security system.

The algorithmic program can be split up in two classes as Range based and Range free.

- ✓ ***Ranged based :***

In this kind of approach the estimation of node location depends on nearness sensing or connectivity data. APIT, Centroid and Distributed algorithm is used in this class

- ✓ ***Range free :***

In this case the estimation of the distance between nodes are measured by few factors as like as like as Time-of-Arrival of signal (ToA), Time-Difference-of-Arrival (TDoA), Received Signal Strength (RSSI),Angle-of-Arrival (AoA) and Time of Flight (ToF).

2.2: Technology

In localization methods some sensors are spread through an area whose location or position are unknowing. In the case of known position for a sensors node is usually depicted as an ANCHOR node. It's use for recognizing the unknown location of a node. To measure the location of a sensors data such as RSSI, distance and time difference of arrival. For the precision the measuring strategies is very crucial. As priory data the anchor node position can found manually by placing it into known position.

2.3: Measurement proficiencies

In a network for measuring sensor given information are obtained by angle-of-arrival of signal (AoA), time-difference-of arrival (TDoA) and also Receive signal strength indicator (RSSI).

The measurement methods are almost closest to the localization algorithm. Depending on the technique has used for measuring, can be varies the localization algorithm.

Almost all of the present methods to find location consist of two basic phases:

- ✓ *Angle (or Distance) estimation and Angle (or Distance) combining*

For estimating the distance between two nodes are as follows:

2.3.1: Angle-of-Arrival Signal:

The Angle-of-Arrival of signal found by using mainly two methods: ***1)*** Amplitude response of receiver antenna's ***2)*** Phase response of the receiver antenna's.

Angle-of-arrival signal methods using phase interferometry is depend on the phase difference between arrivals of wave front. To accomplish this technique an array of antenna is needed. Amplitude response is measured in the side of receiver antenna. The amount of the measurement unit can be smaller with respect to the wavelength of the signal. To perform this technique distinctive anisotropic antenna and beam pattern have been used. The direction representing to the highest signal strength has accepted as direction of transmitter while receiver antenna beam was rotated. To resolve the potential problem in rest to the signal strength variation which introduced by anisotropy non-rotating omnidirectional antenna can be introduce at the receiver. The variation of the signal strength can be excluded by normalizing the strength received by anisotropic with respect to signal strength experienced by the non-rotating omnidirectional antenna.

Angle-of-arrival signal depend on a direct line-of-sight (LOS) path between the transmitter and the receiver. Shadowing and multipath also acted upon on the signal. Multipath component can causes a very large error in the Angle-of-arrival signal. To resolve this kind of problem maximum likelihood algorithms are introduced.

AoA is the angle between the propagation direction of an incidental wave and reference direction, which are called orientation. Orientation is defined in degrees in a clockwise direction from the North. The AoA gives real value when it's indicating to the north or just orientation is zero degree.

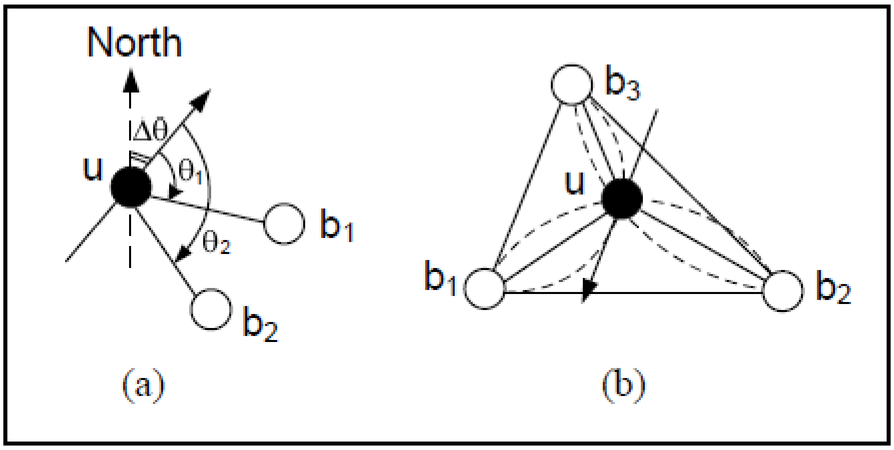


Figure 3: AoA localization: (a) With orientation; (b)Without orientation

- When orientation of unknown node is known, we can have:

θ_1: *AoA the signal goes through node b_1 to node U*

θ_2: *AOA the signal goes through from node b_2 to node U*

$\Delta\theta$: O*rientation of the U*

The absolute value of AoA from b_1 and b_2 = $(\theta_k + \Delta\theta)(mod 2\pi)$ {k = 1, 2}

- In case of absence of the orientation for unknown node cannot derived absolute AoA, to overcome this difference of the AoAs are considered. In the figure 1(b) the angles b_1ub_2, b_1ub_3 and b_2ub_3 calculated from the information of the relative AoAs. Where all angles delimited by the same chord as equal.

2.3.2: Time-Difference-of-Arrival Signal:

It's used for calculating the difference between the received arrival times of signal. Receiver contemporized time and technique is accomplished to comparison the time of the receiver.

The approximation techniques subtracting the arrival time of signal between receiver measures from two separate base stations to derive relative TDoA or by cross-correlation where correlation between received signal at one base station and another base station. To determine the time lag between two versions of signal pattern matching algorithm called as cross correlation has maximum values with zero (0) lag time. The various time lag cross correlation index increases lag time while it was measuring with unlike lag time, in the time of identical signal receives.

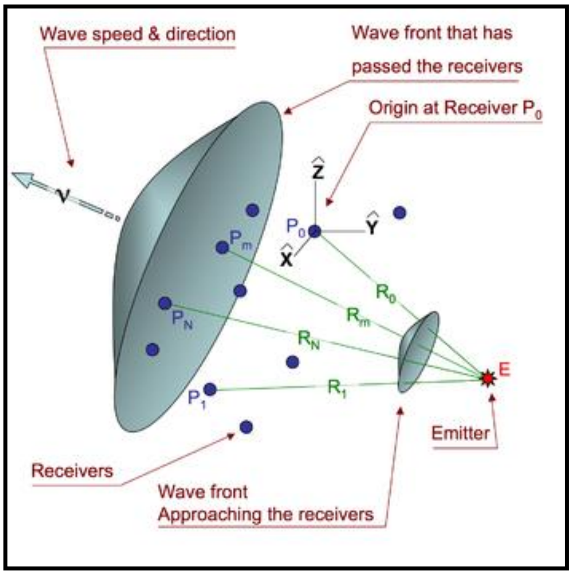


Figure 4 Geometry of TDoA

Usually the time difference is measured in hyperbolic modality as follows:

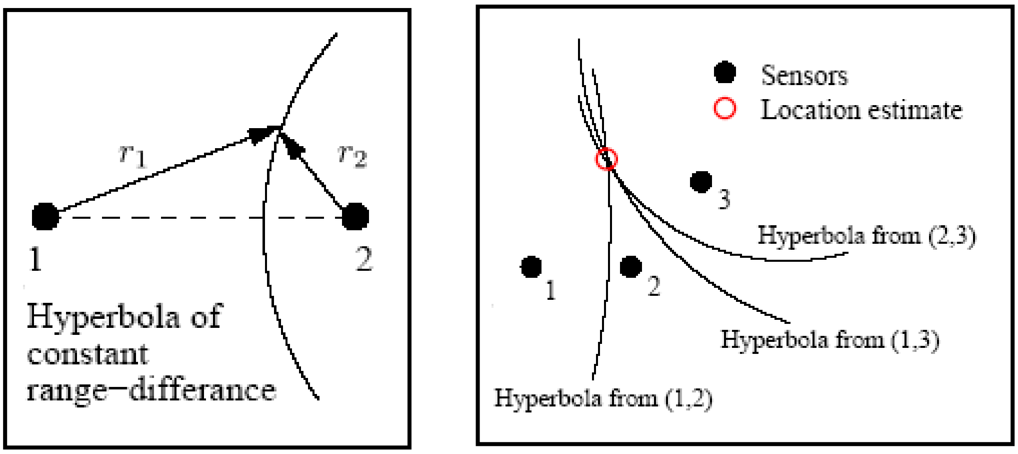


Figure 5 : Hyperbolic Theory

The hyperbolic the set of points from two sensors at a constant range-difference ($C_0\Delta t$) is hyperbolic location. Each pair of sensor provides a hyperbola on the area of transmitter lies. In the figure 5 red circles represent the location estimation as intersection of hyperbola.

Assuming unknown transmitter at point E and N+1 known receiver in P_k, where k = {0….N}.

$$P_m = (x_m, y_m, z_m) \qquad 0 \leq m \leq N$$

The distance between transmitter and one of the receiver is R:

$$R_m = \left|\vec{P}_m - \vec{E}\right| = \sqrt{(x_m - x)^2 + (y_m - y)^2 + (z_m - z)^2}$$

$$R_0 = \sqrt{x^2 + y^2 + z^2}$$

T_m is transiting time, v is velocity of wave, and t_m is time difference of a wave front touching each one of receiver, therefore:

$$vt_m = v\,T_m + v\,T_0 = R_m - R_0$$

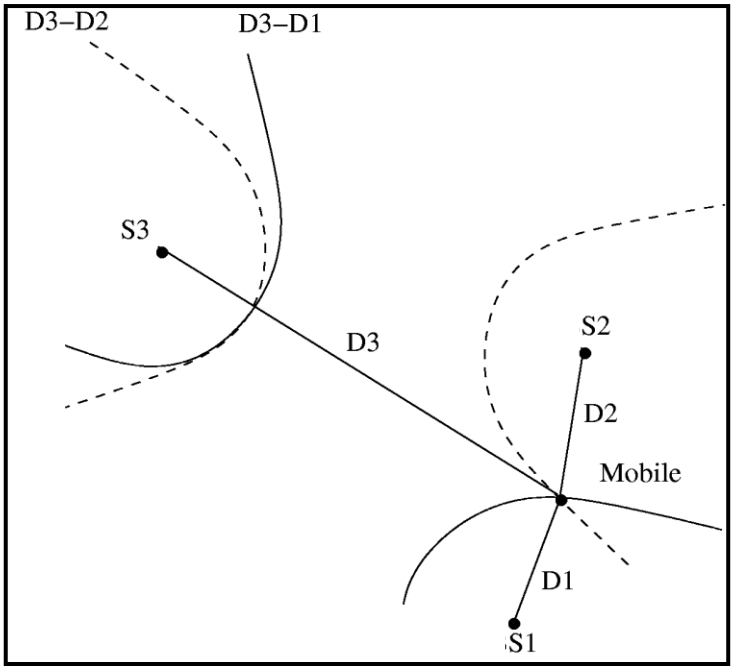


Figure 6 : TDoA Positioning.

The anchors node (sensors node) are S1, S2 and S3 and mobile is a unknown moving object which position should be find out:

$$D_{32} = \sqrt{(x_3 - x_M)^2 + (y_3 - y_M)^2} - \sqrt{(x_2 - x_M)^2 + (y_2 - y_M)^2}$$
$$D_{31} = \sqrt{(x_3 - x_M)^2 + (y_3 - y_M)^2} - \sqrt{(x_1 - x_M)^2 + (y_1 - y_M)^2}$$

Time-Difference-of-Arrival Signal (TDoA) can function on following two modes:

- The multiple reference pulsations received by the moving object and it measure the TDoA
- The multiple fixed nodes received a reference pulse which transmitted by moving object and so the fixed nodes must be send on to the TDoA data to workstation. Then to measure it's runs the hyperbolic location algorithms.

2.3.3: Time-of-Arrival of signal:

It calculates the total elapsed time to send the signal from the source to the receiver via a link. This can be done by measuring the time for an instruction transmitted from base station to mobile object or simply by responds from mobile object to an inquiry. The total execution time is sum of the round trip signal delay and any kind of response or processing delay into the mobile unit. When the processing delay is known with adequate accuracy then it can be subtracted from total measured time which will derived the total delay of round trip.

In this method the target location is found by the intersections of the circles which one made by the measurement of ToA for the transmission with more than three sensors. To minimize the error in situation which circles does not intersect in a unique point. It will conduct large estimation errors while arriving signal at sensors because of reflections in case of no Line-of-Sight (LOS) path.

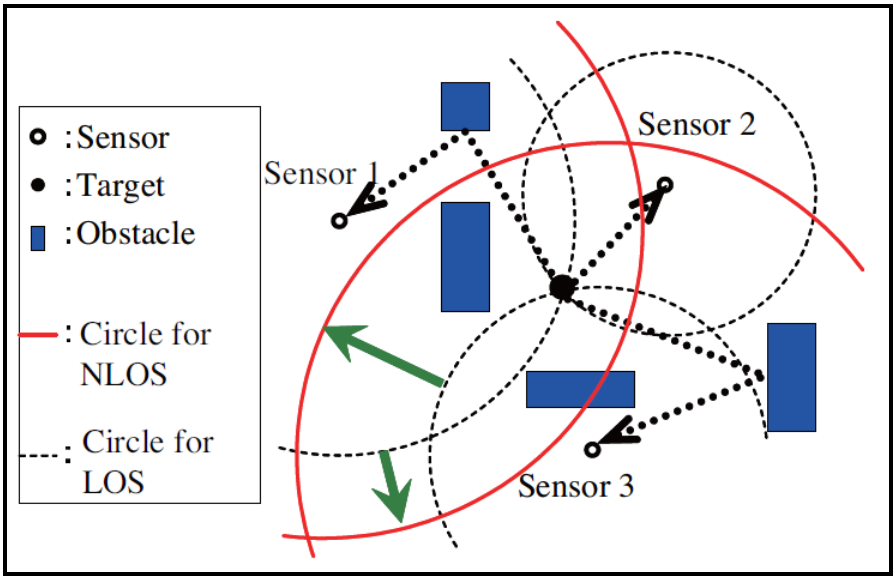


Figure 7 : ToA measurement under LOS and NLOS position

In the case of two dimensional sensor filed if n sensors and one target are present, ToA measurement determines a centered of circle at the sensor for each of them. The radius is found by multiplying the ToA measurement with the light speed. When there is absence of Non-Line-Of-Sight (NLOS) errors and noise then target must be located on each circle. The position of target is the same as the intersection point of three circles.

$$R_k = \sqrt{(x - x_k)^2 + (y - y_k)^2} \quad , \quad k = 1,2, \dots , n$$

- (x, y): *Real position of the target*
- (x_k, y_k): *Position of the sensor k*

The ToA measurement for sensor k as follows:

$$t_k = \frac{R_k}{v_c} + w_j + u_k$$

- W_j: *measurement noise of ToA*
- U_k: *range error of NLOS*

w_j is additive Gaussian white noise with normal probability distribution function $N(0,\delta_j^2)$ with zero-mean and the variance of the ToA measurement noise δ_j^2.

2.3.4: Received Signal Strength Indicator:

This Received Signal Strength Indicator usually measures the power of the signal at the receiver. The effective propagation loss calculated depending by knowing transmit power. It is anchored on the Power observations. The sensor estimate received signal power by integrating signal power at a certain frequency band. Measurements of the transmitting power of an antenna RSS provides a wide range of data. Therefore RSSI are measurements of them power present into received radio signal. To have predefined frequency band it can be used in a wide range based application. To obtained perfect RSSI data the gain of the antenna are considered and also frequency of the emitting radio signal of a transmitter.

There are some factor can regulate the RSSI in an indoor environment application. The relationship exists between transmitted power (P_t) and received power (P_k) of wireless signal, the distance among nodes.

$$(P_k) = P_t \left(\frac{1}{d}\right)^n$$

$$\text{Hence,} \quad 10\log P_k = 10\log P_t - 10n\log d$$

d: distance from sending to receiving nodes

10logP: expression of power converted to dBm

$$\rightarrow \quad P_k(dBm) = A - 10.n.\log d$$

Therefore the relationship between the RSSI and d can be by A and n parameters.

The most frequently used methods for combining phase is:

2.3.5: Maximum Likelihood Estimation:

The *Maximum Likelihood (ML) methods* estimate the position of a node by minimizing the differences among the measured and estimated distances.

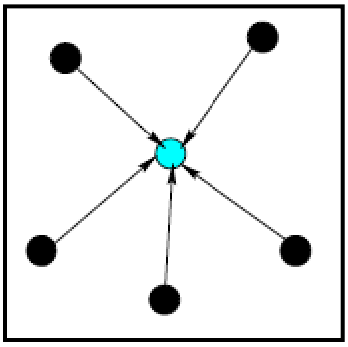


Figure 8 : Maximum Likelihood (ML) Estimation

Here some nodes know their location (either because they are fixed or by using GPS) and are called beacons or anchor nodes, and some other nodes called sensor nodes, estimate their location using the information they receive from the beacons.
When an unknown node estimates its position, it turns into a beacon node and propagate its estimated position to other nearest unknown nodes, modifying them to estimate their positions. This is iterative process until all the unknown nodes that satisfy the requirements for multilateration obtained an estimate of their position.

- *Atomic Multilateration:*

It's behaves as the basic case when an unknown node can estimate its position while it range around at least three beacons.

- *Iterative Multilateration:*

The iterative multilateration algorithm uses to estimate node positions in an ad-hoc network. It estimates the position of the unknown node using atomic multilateration under the maximum number of beacons. To obtain best accuracy and faster convergence starts from the unknown node with the maximum number of beacons at a central location into entire network topology.

- *Collaborative Multilateration:*

With random distribution of beacons in an ad-hoc network ,It can be happed the conditions for atomic multilateration does not met that's mean unknown node may not have three neighboring beacon nodes that's way it will not be possible to estimate position using atomic multilateration. In such kind of condition node may estimate its position using location information over multiple hops in a process is define as collaborative multilateration. A node can determine its location when it has sufficient information to form an over-determined system of equations on a unique solution set. Moreover for the rest of additional unknown nodes the position can measure by solving simultaneous quadratic equations.

Chapter 3: Received Signal Strength Indicator (RSSI) and Inertial Measurement Unit (IMU)

3.1: Introduction

Wireless sensor network such kind of system which receives and transmits radio signals through air, it makes the communication channel. To send signals throughout long distance wireless communication used electromagnetic waves.

3.2: Radio Wave

Radio wave is electromagnetic wave has electric field and magnetic field which oscillating on period. When the distance increased for source the amplitude of the diffusion wave decreased while wave travels through a medium.

Some terms are very frequently used in radio engineering such as:

- ✓ ***Period:*** The total time required for finishing one wave cycle or total time elapsed from start of the wave to end of the wave is defined as period.
- ✓ ***Frequency:*** The total number of completed cycles in a second is defined as frequency.
- ✓ ***Polarization:*** It's the direction of the electrical field vector.
- ✓ ***Bandwidth:*** The amount of the information or data can receive or transmit.

3.3: ISM band

Industrial Scientific and Medical(ISM) scope for using radio frequency energy for scientific research, industrial and medical research. There are some examples of its applications with these band are radio-frequency process heating, Microwave oven and medical diathermy machines. In spite of, all these features recently it used most for low-power and short-range communication systems.

The Industrial Scientific and Medical (ISM) bands specified by the ITU-R such as:

Range of Frequency		Bandwidth	Midpoint of Frequency	Availability
6.765 MHz	6.795 MHz	30 KHz	6.780 MHz	Issues for local acceptance
13.553 MHz	13.567 MHz	14 KHz	13.560 MHz	Worldwide
26.957 MHz	27.283 MHz	326 KHz	27.120 MHz	
40.660 MHz	40.700 MHz	40 KHz	40.680 MHz	
433.050 MHz	434.790 MHz	1.84 MHz	433.920 MHz	Region 1 only and subject to local acceptance
902.000 MHz	928.000 MHz	26 MHz	915.000 MHz	Region 2 only (With Some Exceptions)
2.400 GHz	2.500 GHz	100 MHz	2.450 GHz	Worldwide
5.725 GHz	5.875 GHz	150 MHz	5.800 GHz	
24.000 GHz	24.250 GHz	250 MHz	24.125 GHz	
61.000 GHz	61.500 GHz	500 MHz	61.250 GHz	Issues for local acceptance
122.000 GHz	123.000 GHz	1 GHz	122.500 GHz	Issues for local acceptance
244.000 GHz	246.000 GHz	2 GHz	245.000 GHz	Issues for local acceptance

Table 1: The industrial, scientific and medical (ISM) radio bands

3.4: Transmission Model

Radio signal transmission model comprised with Transmitter antenna, Receiver antenna/Transceiver antenna and transmitter or receiver module.

At first to avoid the loss of propagation over the medium, data should be amplified to send across the transmitter antenna. The data amplification is needed at the receiver end too.

There are plenty of wide range wireless module for transmitter and receiver with external hardware (Example: Microcontroller etc.) which have been followed through pre-amplifier and antenna gain.

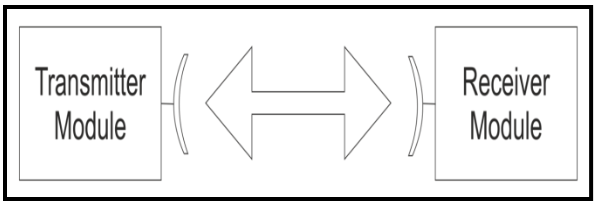


Figure 9: Radio Signal Transmission Connection

There are several propagation model do exists like indoor and free space propagation model which has strong relationship among the signal radiated to signal received just as function of distance and some others variable. Due to diversity in characteristic of transmission and environmental model the propagation model can differ to model data which followed by some fundamental stage.

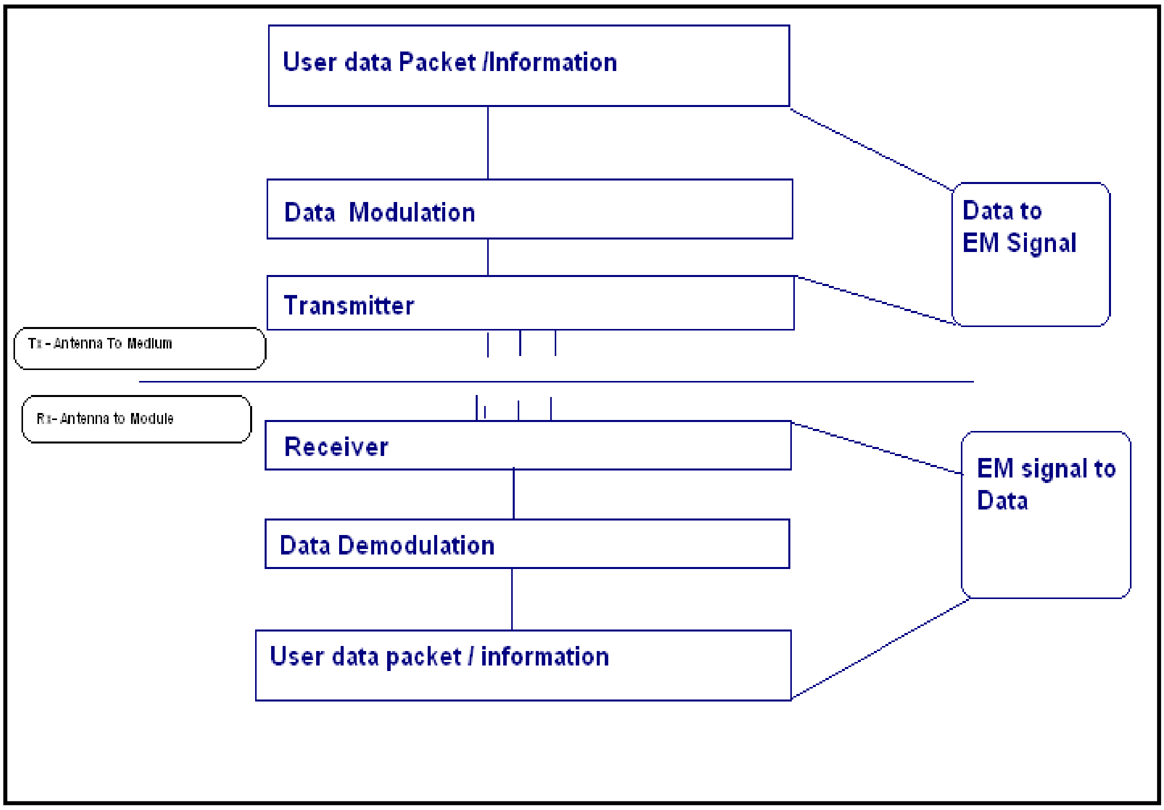


Figure 10: Transmission Model

The radio system module comprised with a transmitter which have to be reliable to transmit radio signal like electromagnetic wave. From given figure we can depicted that model consists a T_x-Antenna which transmit data packet, the information or data packet pre amplified or the digital data is modulated in advance of transmitting it.

Conversely R_x-Antenna does appear in the receiver sections which acquire modulated information over electromagnetic signal. Here signal are pre amplified before the data is demodulated.

3.5: Signal Power Studies

There are several barriers due to radio propagation which can vary significantly depending on the region, frequency of operation, speed of the mobile terminal, interference sources and some other dynamic elements. In open region radio propagation is much differs from radio propagation within indoor and urban areas. In open areas through small distances/free space, the strength of signal decreases as the square of the distance. In other region, the strength of the signal often fall down with higher rate as a function of distance dependent on the environment and radio frequency too. In urban areas, the shortest direct path (the line-of-sight

{LOS} path) across the transmitter and receiver is normally blocked by buildings and other terrain features outdoors. In addition in indoor areas, walls, floor and interior things within buildings embarrass LOS communications. This kind of situation is defined non-LOS (NLOS) or obstructed LOS (OLOS). The signal strengths of these paths dependent on the distance they have been traveled, the obstacles they reflected from or passed through with, the environment architecture and the position of objects throughout the transmitter and receiver.

In open space propagation discovered that the radio signal strength fall down as power α of the distance (d) defined like power-distance gradient or path-loss gradient. Thus for the transmitted power of P_t with d distance in meters then the signal strength are proportional to $P_t\ d^{-\alpha}$. It's a large scale model which power decline exponentially with a distance in free space is given by:

$$P_r = \frac{P_t \,.\, G_t \,.\, G_r \,.\, \lambda^2}{(4\pi)^2 \,.\, d^2 . L^2}$$

Hence,

P_r: *Received power*

P_t: *transmitted power*

G_t: Gain for *transmitter antenna*

G_r: gain for *receiver antenna*

d: distance between T_x*(transmitter) and* R_x*(receiver)*

λ = *c/f : carrier wavelength*

L: some *other hardware losses (L ≥ 1)*

where, c: speed of light

f: frequency of radio carrier

The antenna gain associated with effective aperture(A_e):

$$G = \frac{4\pi . A_e}{\lambda^2}$$

Moreover, attenuation can affect the power of the signal. The Path Loss Model in the large scale propagation, Shadow Fading is effective in the wireless channel and fading model is useful for small scale.

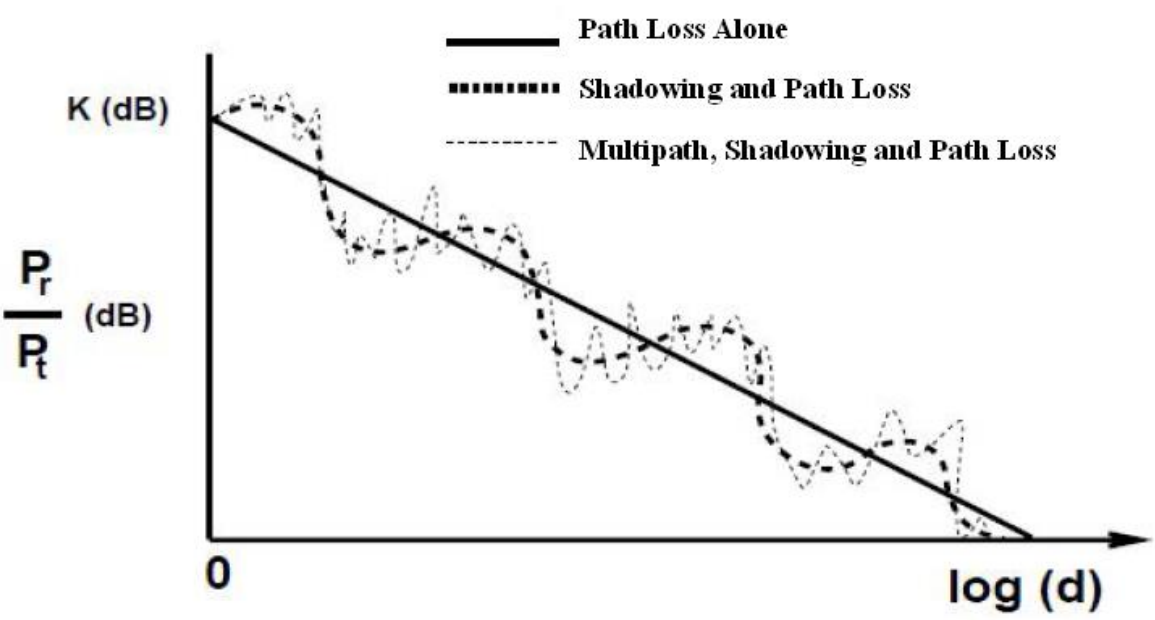


Figure 11 : Path Loss, Shadowing and Multipath versus Distance

Path Loss:

The signal passes over from transmitter to receiver antenna with a transmitting power in a distance. During the signal transmission power decline with respect to the distance due to signal propagation across the space is called as Path Loss or Power-distance. Path loss is occurred different kinds of reasons like free-space loss, aperture medium coupling loss; refraction and absorption. The signal may radiate through multipath from transmitter to a receiver. Usually path loss exponent represent the path loss such as in free space 2 is for signal propagation and 4 for lossy environment. Path loss i.e. signal attenuation measured in dB with positive quantity.

Path loss in free space derived as follow:

$$PL(dB) = 10Log\left(\frac{P_t}{P_r}\right) = 10Log\left[\frac{G_t\ G_r\ \lambda^2}{(4\lambda)^2\ d^2}\right]$$

In path loss sensible for values of d what in the far field, is the distance outside of d_f which is referred to highest linear dimension (D) of the antenna wave length (λ) and aperture:

$$D_f = \frac{2D^2}{\lambda}\left(D_f \gg D\ \&d_f \gg \lambda\right)$$

The reference distance d_0 known before perceived power references are used (Model is not valid for d=0):

$$P_r(d) = P_r(d_0)\left(\frac{d_0}{d}\right)^2 \qquad d \gg d_0 \gg d_f$$

Usually Path loss expressed in dB:

$$PL(dB) = 10nLog_{10}(d) \quad + \ C$$

Where, PL: path loss in decibels; n: path loss Exponent; d: distance between the transmitter and the receiver in Meter; C: constant which accounts for system losses

Almost all of the propagation models used combined of analytical and empirical techniques where empirical techniques are based on measured information or data, it consider all known and unknown propagation phenomena. Depending on the operating environment and parameters during the measurement process can decide this model is valid or not. With respect to ToA, TDoA and AoA with RSSI which needs less implementation complexity and low-cost so path loss model is more worthy in wireless sensor network for a node. According to the convention of RSSI, we can derive following relationship between power of transmitted and received signal with a distance:

$$P_r = P_t.(\frac{1}{d})^n$$

$$\rightarrow \ 10\log P_r = 10\log P_t - 10\,\text{nlog}\,d$$

- ✓ P_r: is the received power
- ✓ P_t: is the transmitted power
- ✓ d: the distance between transmitter and receiver node
- ✓ n: is the transmission factor whose value be determined by the propagation environment.

10logP_r , is the expression of the power in decibel (dBm), therefore from above equation we get:

$$P_R(dBm) = A - 10nlogd$$

The relationship can be derived among the strength of the received signal and distance of the signal transmission by the values of parameters A and n.

Shadow Fading:

The path loss depends on the environment, the location of object and antenna height etc. during the transmission path signal strength can vary due to all those obstacles this problem is define as shadowing or slow fading.

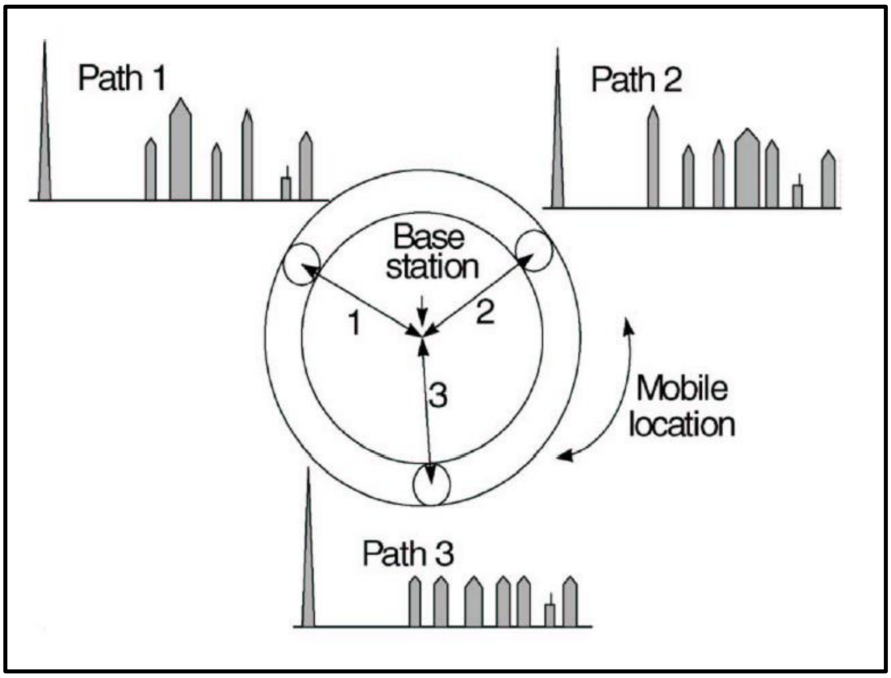


Figure 12: Variation of path

In respect to Log-distance path loss the average received signal power decrement logarithmically with distance:

$$PL(d) \propto (\frac{d}{d_0})^n$$

$$\overline{PL}(dB) = \overline{PL}(d_0) + 10n\log(\frac{d}{d_0})$$

Where n is the path loss gradient or exponent which may have diversity in values on different environment as below:

Transmission Environment	Path Loss Exponent (n)
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Table 2: Values for Path Loss Exponent

The actual received signal strength will vary around the mean value due to location is often referred to as shadow fading or slow fading because very often the fluctuations around the mean value are caused due to the signal being blocked from the receiver by buildings (in outdoor areas), walls (inside buildings) and some other objects in the environment. To resolve such problem real value has established as random and distribution as Log-normal in dB approximately the mean distance dependent measure:

$$PL(d) = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma \quad \text{(I)}$$

X_σ: Gaussian Random Variable with zero-mean in dB with σ standard deviation in dB

The Log-normalX_σ, provides the shadowing effect which occupied across numerous measured signal strength at position with equal $T_x - R_x$ separation.Therefore, the antenna gain with PL(d) we get:

$$P_r(d) = P_t - PL(d) \text{ Where, } P_r \textit{ and } P_t \textit{ in dBm}$$

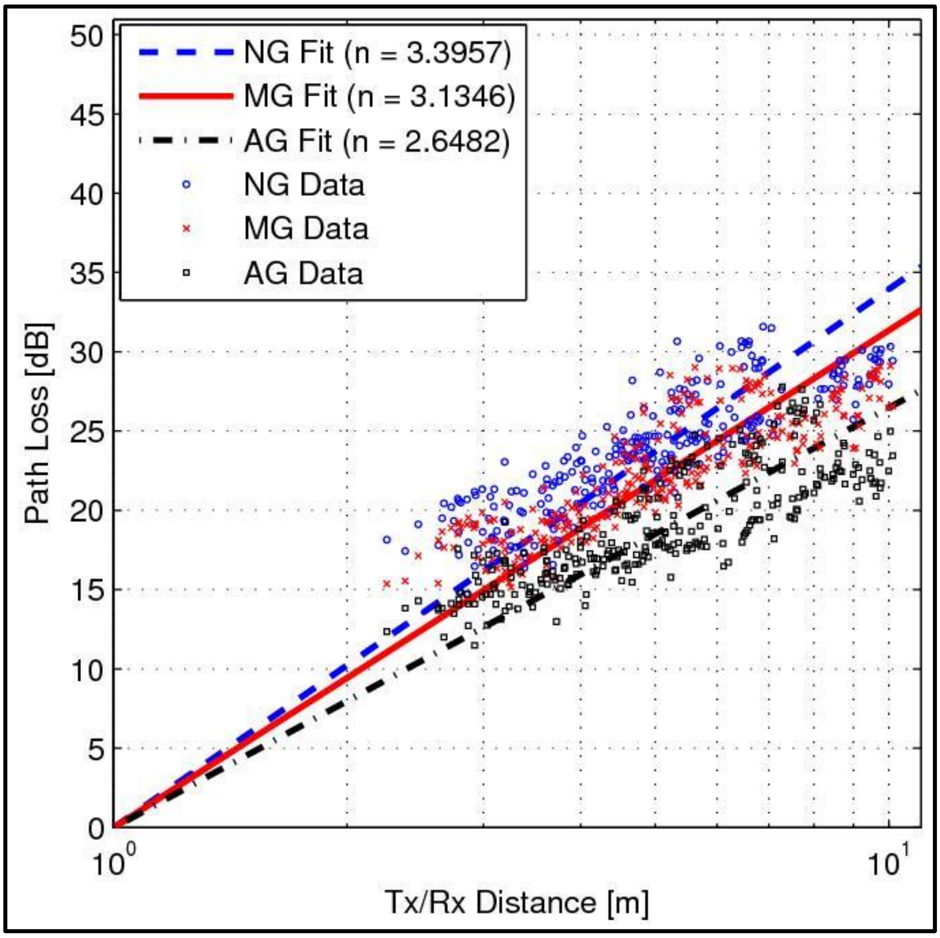


Figure 13: Log-normal Shadowing

For Log-normal Shadowing the probability that the received signal level exceed a certain level while $PL(d)$ is a normally distributed random variable:

$$Q(z) = \frac{1}{\sqrt{2\pi}} \int_{z}^{\infty} e^{-\frac{x^2}{2}} dx \; = \frac{1}{2} \left[1 - \operatorname{erf}\left(\frac{z}{\sqrt{2}}\right)\right]$$

The probability for received signal in dB for beyond a value γ:

$$\Pr[\, P_r(d) > \gamma] = Q\left(\frac{\gamma - \overline{P_r}(d)}{\sigma}\right)$$

The probability for received signal in dB for fall down below γ:

$$\Pr[P_r(d) < \gamma] = Q\left(\frac{\overline{P_r}(d) - \gamma}{\sigma}\right)$$

The log-normal probability density function is:

$$f_{LN}(x) = \frac{1}{\sqrt{2\pi}\sigma x} \exp(\frac{-(\ln x - \mu)^2}{2\sigma^2})$$

μ: *is mean for received signal strength*

σ: *Standard deviation*

Using experimental experience across signal strength group (d, RSSI) we get following function:

$$\sigma(d) = Xd^3 + Yd^2 + Xd + e \quad \text{(II)}$$

Where the coefficient X, Y, Z and e are undetermined but this can be dynamically adjustable according to transmission environment.

By placing equation (II) into equation (I) we get:

$$PL(d)(dB) = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10\eta \log\left(\frac{d}{d_0}\right) + \sigma(d)X$$

The function $\sigma(d)$ makes Log-normal shadowing model dynamically control based on the difference distance the error of this function.

Fading:

Fading is fluctuation of amplitude, phase and multipath delays of a signal across a short time or distance. The constructive and destructive interference across different version of the signal arrive at the receiver at different time is the cause of fading. This effect held due to multipath channel, different result like changing in signal strength among small distance of time, having random frequency modulation since Doppler Effect for each multipath due to propagation delay.

By Doppler the difference in path length by wave is:

$$\Delta l = d \cos\Theta = v \, \Delta t \cos\Theta$$

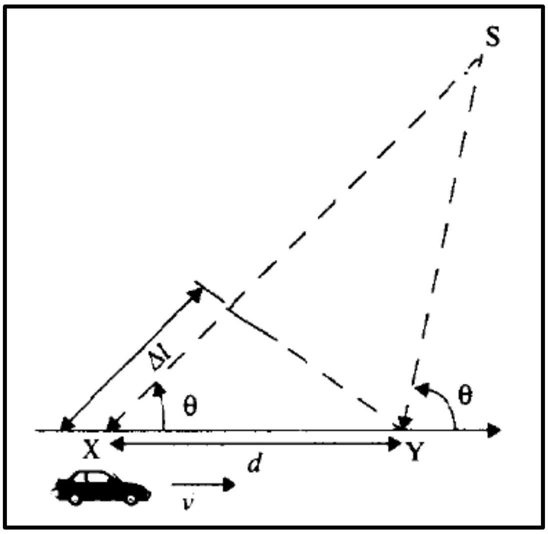


Figure 14: Doppler

Phase change in received signal since path length difference:

$$\Delta\phi = 2\pi\Delta l/\lambda = 2\pi.v.\Delta t/\lambda \times \cos\Theta$$

Apparent change in the frequency – Doppler shift as follows:

$$fd = \Delta\phi/2\pi\Delta t = (v/\lambda)\cos\Theta$$

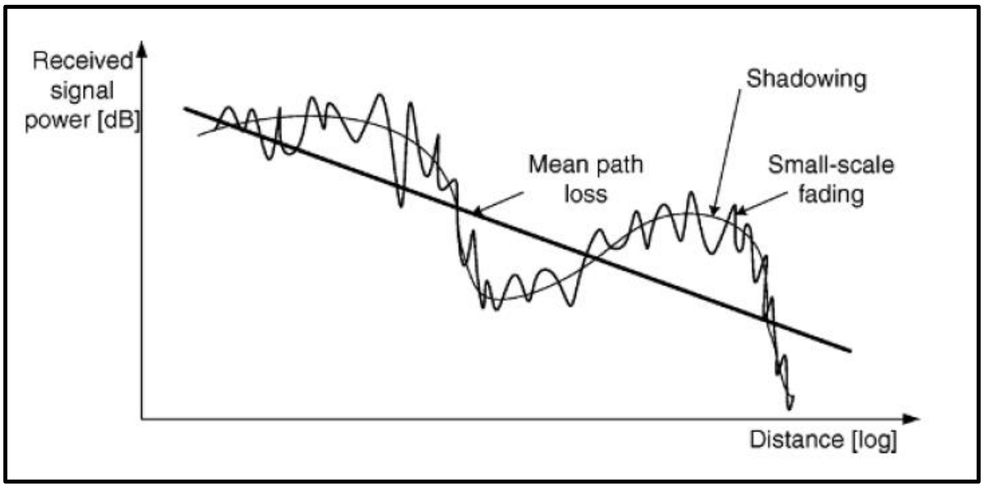


Figure15: Large-scale fading vs. Small-scale fading

3.6: Radio Propagation Tools

There are three main propagation tools for indoor and outdoor environment.

Reflection:

Radio wave may have contact with a material it will reflect so that its look likes for light. The angle will keep up means; the same angle will be reflected at where angle of the signal will hits to the surface. Reflection creates a main issue in indoor application since lots of and different types of substance can appears.

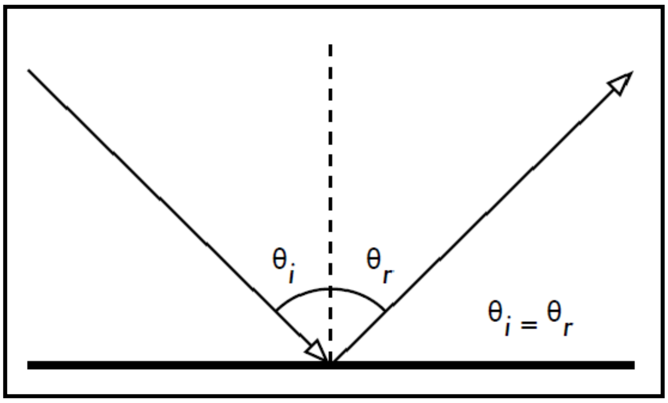


Figure 16: EM signal Reflection

Diffraction:

The original signal wave can be bend because of the sharpness of object like corner this effect is defined as diffraction.

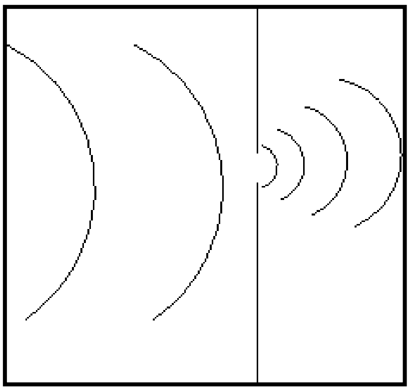


Figure 17: Diffraction of EM signal

Because of diffraction the wave will "bend" near to corners or throughout an opening in a barrier. It related to different phenomena when a wave encounters an obstacle and the diffraction is the apparent of waves near to small barriers.

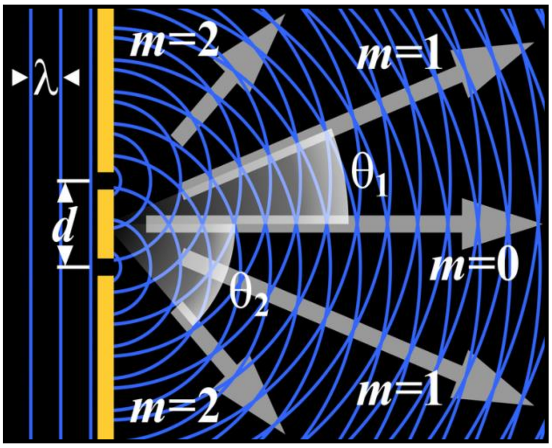


Figure 18: Interference pattern for two-slit diffraction

Scattering:

Scatter rays to all direction like spherical waves for rough surface such as vehicles in outdoor environment then its observed scattering. Propagation into diverse direction can decrease power level.

3.7: Inertial Measurement Unit (IMU):

By using inertial sensors localization system provides relative information (gyroscope and accelerometer). Also this sensor is providing absolute information (magnetometer and RSSI measurement). A brief simulator of the inertial system is depicted where mathematical models of all sensor parts are given. It's used to design and experiment the developed localization algorithm for finding position of inertial navigation unit.

Trajectory generation of the INS

For simulation moment and rotation of the INS unit the trajectory and rotation are given in parametric as follows:

$$\mathrm{x} = f_x\,(\mathrm{t})$$

$$\Phi = f_{\Phi}(\mathrm{t}) \qquad \text{(a)}$$

Where, $x = [x_\omega, y_{\omega,} z_\omega]^T$ and $\Phi = [\Phi_\omega, \theta_\omega, \psi_\omega]^T$ are the unit positions and Euler angles, respectively.t: is continuous time. Velocity, acceleration and angular rates of the unit achieved by:

$$v = \frac{d}{dt} f_x\,(t)$$

$$a = \frac{d^2}{dt^2} f_x\,(t) \qquad (b)$$

$$\omega = \frac{d}{dt}\, f_{\Phi}(t)$$

Rotation matrix R_{ω}^{i} from the worlds coordinates to the local units coordinates. It's defined by first rotating world coordinate frame around its z axis for ψ_{ω} then for θ_{ω}around new y axis. Finally for Φ_{ω}around new x-axis as bellow:

$$R_{\omega}^{i} = R_x R_y R_z \;=\; \begin{bmatrix} C_{\theta_\omega}\, C_{\psi_\omega,} C_{\theta_\omega} S_{\psi_\omega}, -S_{\theta_\omega} \\ S_{\Phi_\omega} S_{\theta_\omega} C_{\psi_\omega} - C_{\Phi_\omega} S_{\psi_\omega}, S_{\Phi_\omega} S_{\theta_\omega} S_{\psi_\omega} + C_{\Phi_\omega} C_{\psi_\omega}, S_{\Phi_\omega} C_{\theta_\omega} \\ C_{\Phi_\omega} S_{\theta_\omega} C_{\psi_\omega} + S_{\Phi_\omega} S_{\psi_\omega}, C_{\Phi_\omega} S_{\theta_\omega} S_{\psi_\omega} - S_{\Phi_\omega} C_{\psi_\omega}, C_{\Phi_\omega} C_{\theta_\omega} \end{bmatrix}$$

Where, c and s stand for cosine and sine function. Rotation matrix R_{i}^{ω} from the local INS unit coordinates to the world coordinates.

$$R_{i}^{\omega} = \; {R_{\omega}^{i}}^{T} \qquad (c)$$

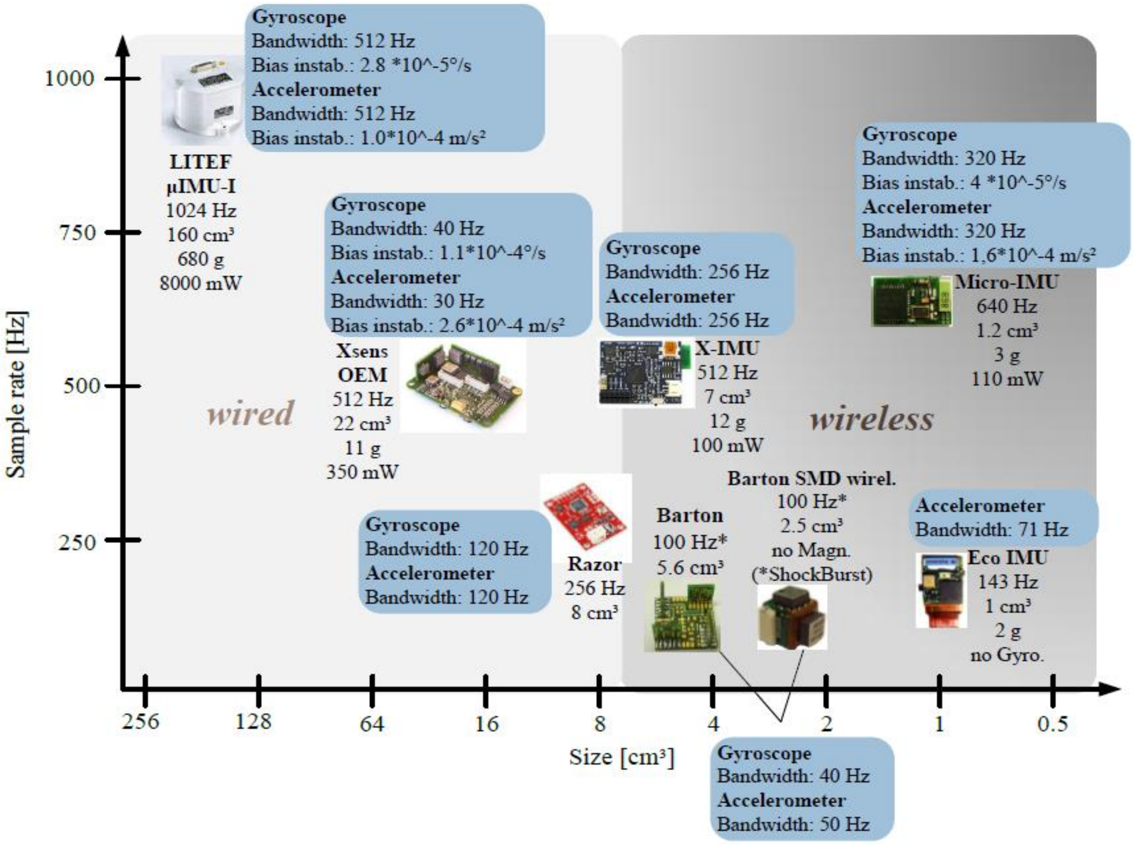


Figure 19: Comprehensive view of size and data performances of IMUs.

3.7.1: Accelerometer Model:

Measured acceleration a_m of tri-axis accelerometer in local sensor coordinates frame is completely based on translational acceleration a. This acceleration vector because of gravity $g = [0, 0, 9.81]^T$ and also such acceleration according to radial acceleration as bellow:

$$a_m = R_i^{\omega T} \ (a + R_e^{\omega} \cdot g + \omega \times v) \ + a_{bias} \ + a_{noise} \quad (d)$$

Where, R_e^{ω}: is the rotation matrix (direction cosine matrix (DCM)). R_i^{ω} is rotation matrix from the local inertial unit coordinates to the world coordinates. ω : is the rotational velocity of the unit given. v: is translational velocity. a_{bias} : is bias part. and a_{noise} : is normal distributed noise.

3.7.2: Gyroscope Model:

Measured angular rates ω_m of tri-axis gyroscope as follows:

$$\omega_m = \omega_i + \omega_{bias} \ + \omega_{noise} \quad (e)$$

Where, ω_i : is true angular rates of the local gyroscope frame. ω_{bias} : is bias part. ω_{noise} : part is normal distributed noise. Considering the inverse DCM matrix R_i^{ω} and its time derivative a skew symmetric as

$$\omega_{skew} = \ R_i^{\omega T} \frac{dR_i^{\omega}}{dt} \quad (f)$$

And finally

$$\omega_i = [\omega_{skew}(3,2), \omega_{skew}(1,3)\ , -\omega_{skew}(1,2)]^T$$

3.7.3: Magnetometer Model:

Magnetometer measures the strength and direction of the earth magnetic field. It's also distributing magnetic fields from electrical devices. Earth magnetic field vector B_{true} for some place on Earth (e.g. 10 x 10 km) can be about to a constant in earth fixed coordinates. For measuring the magnetic field B_m in local INS coordinates is defined as follows:

$$B_m = R_i^{\omega^T} \; R_e^{\omega} \, B_{true} + B_{bias} + B_{noise} \quad (8)$$

Where, B_{bias} : is bias part, B_{noise} : Distributed noise, R_e^{ω} : is the rotation matrix.

Chapter 4: Literature review and observations

4.1: Introduction

Signal propagate through environment which has various matters what's induces attenuation. Many researchers used RSSI for localization to deals with such kind of problems. The average statistical model and Zero-mean Gaussian model based on the distance across the fixed nodes are commonly used to optimize the RSSI values [11]. There are several beacon-free methods with the inertial measuring units (IMUs) suggested for the localization of persons [44].

4.2: Literature overview

There is various proposed location estimation protocols [5, 7, 8, 9, 23, 24, 25, 26, 27] authors proposed the estimation of the location based on the information received from the beacons nodes. This information consists of the beacons' coordinates and features of the beacon signal like the received signal strength indicator (RSSI) or time-difference-of-Arrival (TDoA).Moreover, other protocol [26] are based on the capability of the nodes to sense the angle from which a signal is received. According [38] presented a solution for aerial localization and [22] proposed a solution where the localization is based on adopting slightly different periodic signal frequencies which is very competitive and achieves very good precision but the computations used are very intensive.

In [6] authors discover a new method for localization according to mobile anchors. In their procedure used different components as: **Sink Node:** This node collect sensing data covered from all the sensors. Its transmit data to the task manager. **Sensor Node (Mobile Beacon):** Its position is as unknown and the output of the localization method will hold its position. **Mobile Anchor Node:** This node equipped GPS may useful to find position in real time. Authors introduce this procedure in two classes: **1)** based on range-based schemes needed either node-to-node distances or angles for estimating location.Such kind of data achieved by time-of-arrival (ToA), time-difference-of-arrival (TDoA), angle-of-arrival (AoA) and received signal strength indicator (RSSI). **2)** In this case the distance or angle information was not needed for localization.

In addition authors derived a localization mechanism based on geometry conjecture which stands for the perpendicular bisector of chord passed through the center of circle. It's essential to have at least three endpoints on the circle to have various chords when three different mobile anchor nodes pass through the circle of sensor node by cross points we get two different chords in same circle. For extending the performance they have been considering three things like Beacon Scheduling, Chord Selection and Obstacle Tolerance, after enhancement it can tolerate radio irregularity because of some obstacles. They showed the average location error is competing to other range based methodology.

The RSSI value can measure [10] between nodes{ i , j} by considering the power is decreased because of the distance and random variable with zero mean normal distribution, standard deviation representing to the fading effect. The value of probability density functions for the distance calculated for the case line of sight (LOS) between node { i, j}and also non-line of sight (NLOS).To measure the initial value of RSSI in the beginning the propagation model is assumed.

In [11] authors suggested, the raw RSSI value with considering the path is used to keep into an array for sequence of RSSI. To deal the environmental obstacle like multipath diffraction so on, some statistically method can useful with certain restriction. Here author suggested Gaussian distribution model by considering that factor and accuracy. The RSSI value filtered by using Gaussian distribution model then compare with threshold value. When it meets the condition it will preserve on another array after that taken average value for all those RSSI. To minimize the error reference node have been used later on they introduced penalization function which can be solvable with sequential quadratic programming.

Respective approaches uses computationally demanding techniques such as convex optimization [8], system of complex equations [26],minimum mean square error (MMSE) methods [13,33].Where the measurement model does not analyzed well enough and the error assumed to be small enough but in real application is not the same as it should.

In [14] authors propose localization according to logarithmic path loss propagation and statistical average. As their suggestion the distance is calculated by considering the average RSSI value on the logarithmic path loss model and the effectuation of the triangulation method with purpose of localization. With respect to authors view the average value of the RSSI followed by path loss model for the radio wave propagation. Different learning algorithm introduced to specify an conquer model for the propagation like neural network [1] and cluster analysis.

Author [3] has proposed localization method according to clustering the body sensors for heterogeneous wireless sensor network in indoor environment. The prime target was improving the safety of works in risky environments and the most important one is to locate them in safe areas in emergency situation. They used the min-Max as their localization algorithm since it isn't so complex. In their algorithm for each anchor a bounding square box will be constructed which anchor itself is in center of that and edges are double of estimated distance of anchor with the target. If exist three of these boxes the center of their intersection it will be the location of the target point. Here the accuracy of the RSSI based localization method is less but by analyzing application scenario and adjusting a defined method it can be improved.

By their proposal a person is equipped with many different sensors to collect different kinds of information and these sensors can communicate wirelessly with each other to send their packets from gateway. They called as Body Area Network (BAN) or a cluster. This BAN (Body Area Network) or cluster has various sensors like one gateway and one cluster head. All sensors measure the distance between themselves and other clusters with respect to receiving the RSSI signal. But because of degradation of the signal propagation, the receiving RSSI would be different for different sensor node even if they be in same position. In this situation the highest RSSI will be chosen among all RSSI which have been received by all sensor nodes in a cluster.

To measure the distance characterization authors have done several experiments for the RSSI which have been obtained by the sensor nodes in different heights and introduced logarithmic formula according to the different heights.

They appraised the performance by estimating error means, like estimation error-RSS-distance model which had found that the performance of localization not relies on the model. Another estimation error is about localization request packet having been used amount which is the influence of the number of RSSI measurement packets used for localization. Finally estimation error was about the number of involved anchor nodes in each cluster which the result showed that positioning is slightly amended by adding anchor nodes into each reference point.

Jason Small and his colleagues in [15] in propose a lookup-table method for node position triangulation. They carried on data collection to empirically correlate distance to signal strength. The shortcoming of this works is that it necessitates wide survey at various points in a predefined environment and the consequent table size.

Some other researcher and scientist bringing in attenuation constant of weather for measuring the RSSI signal. In [12] preluded received signal power measured taking consideration the logarithm distribution and consider the variance of the shadowing effect for radio signal propagation model under path loss and antenna gain, receiving antenna gain and also transmission power. The received signal strength attenuates within proportion to the negative weather attenuation. The power of the distance between nodes is the location estimation using RSSI values. Also the attenuation constant is derived from a function of the distance of the nodes.

In [4] authors proposed methods based on path loss model for open space propagation and logarithmic path loss of the radio signal. By Consider that value, antenna again, emission power is used to measure the distance. Authors introduce geometric constraints of two-dimensional space of Cayley Menger determinant for compensating the errors of RSSI measurement. For localizing the position have been used the Centroid triangle method.

In paper [16] authors suggested an optimal averaging window length of RSSI samples to deal with fading of the power and mobility of the nodes. By modeling the channel's fading with a Rayleigh distribution, authors achieved a factor (r^2) which multiplies the RSSI samples (ω). They covered a lower bound mean error of 2.5m with ω=50. The principal drawback is that this method is specified for rectangular areas where beacons are positioned optimally. Also they formulate empirical power-distance models based on averaged RSSI measurements surveyed in specific positions. They also introduced some other matter which affecting the received power levels like fading because of multipath, non-line-of-sight, node mobility and sampling too.

Paolo Barsocchi and his colleagues [17] advised a method based on fingerprint and signal propagation modeling. Authors have used anchors node whose position is known before.

Their proposed method is consisted by two phases such as one is training phase and other one is localization phase.

In training phase the anchors node propagate packets which is containing with the identifier. This information has been used by the server to calibrate propagation model. Walls and Floor attenuation is also considered with path loss model. Authors presented the global virtual calibration which produces same parameter for each wall where per-wall virtual calibration offers an attenuation factor for the walls which one straight affect the communication among specific spans of anchors. Heuristic method is used to estimate the propagation model parameters by using the RSSI measurements on grid points in the environment, as it has been done with fingerprinting.

Although most localization systems are designed based on beacons or sensors are being placed as references to estimate the positions of moving objects and consider that are fixed in their locations but we may have inaccurate results while the positions of the beacon changes during the process and localization procedure. In this situation *Beacon Movement Detection (BMD)* would be a good solution to recover this problem [18]. Authors divided the detection process of movement in four categories:

i) Location-Based (LB) strategy: which tries to calculate current location of each beacon's, after that compares the result with its predefined location for deciding if it has been moved or not. This method has excellent detection result if there are many beacons. ii) Neighbor-Based (NB) scheme: beacons will keep track of their neighbor beacons and report their observations to the BMD engine to verify some beacons have been moved or not. iii) Signal Strength Binary (SSB) strategy: changes in the signal strength of beacons will be exploited, in most of the situation this method performs quite well. iv) Signal Strength Real (SSR) scheme: the BMD engine will collects the total amount of reported signal strength changes of each beacon for making decisions. Only the first method assumes that the original positions of beacons are known for the system. Rests of them have no pre knowledge for the original position of the beacons.

They suggested some heuristic methods by mapping the Beacon Movement Detection problem to the vertex-cover problem, it improve the error ratio more than 70 percent in most of the cases for Signal Strength Binary or Real situation.

In [19] authors evoked methods by combining the ToA and RSS weight with path loss exponent's estimation in NLOS environment. To minimize the effects of the NLOS conditions the believable factor algorithm or (BFA) is that kind of weighting algorithm which has good performance in this case nevertheless needs some assumptions which are not favorable for the WSN such as needs of three sensors around the mobile object. According to their method no prior knowledge needed about the path loss exponent for NLOS environment and TOA and RSS measurements has been used.

According to their method the distances is measured with TOA measurements which are weighted by the believable factor (BF).It derived from the difference among the estimated distance with TOA measurements and that with RSS ones. Moreover the path loss exponents estimated for each node by maximum likelihood (ML) manner.

Eventually this algorithm has high localization accuracy beyond the knowledge of path loss exponent.

Some other approaches especially [20, 30, and 36] estimate the position of a node by the RSSI method which is the most realistic model for sensor network communication. In [20] authors used the RSSI error model to analyze the problem of evaluating the ability of the sensor network to locate a sensor node. Also using only the mean of the measurements is not a correct approach because of the lognormal distribution of the distance from the beacon. Furthermore, their proposed method does not take into account the basic parameters of the RSSI model (standard deviation and path loss exponent) so the proposed methods gives incorrect outcome.

In the article [21] Andreas Savvides and his colleagues suggested nodes to dynamically discover their own location by two-phase process: i) Ranging: each node estimates its distance from its neighbors. ii) Estimation: nodes with unknown locations has used the ranging information and known beacon node locations within their neighborhood for estimating their location. For verifying the roaming selection writers executed a comparison between two promising techniques: one is in according to received RF signal strength other one based on the Time of Arrival (ToA) of radio frequency and ultrasonic signals. The accuracy increased the system robustness with centralized implementation for the location estimation. Also they have showed that the accuracy of iterative multilateration was satisfactory for small networks but for large scale network improvement is required.

In article [28] authors employed Log-Normal Shadowing Model (LNSM) can improve the relationship between the RSSI value and distance but the parameter of variance in LNSM is dependents on experiences except self-adaptability. It discovered that the variance of RSSI value varies along with distance regularly by considering a large number sample. Authors also depicted the relationship function of the variance of RSSI and distance and established the log-normal shadowing model with dynamic variance. In addition they used the Least Squares (LS) solution to estimate the coefficients in the model. Finally Log-Normal Shadowing Model with dynamic variance (LNSM-DV) which is a self-adaptable method. It has good practical implication to improve the accuracy of ranging, the accuracy of location and the self-ability of ranging models.

In [29] authors proposed a methodology for PLE estimation in an outdoor environment. Firstly the methodology pairs RSSI measurement expressed in dB in units with distance (L[dB], d[m]). Secondly they used well-known log-distance path loss model to explicate the system of equation. Here, authors calculated propagation losses in two different points with identical conditions (line of sight condition) then it's derived as a two linear equation systems:

$$L_1[dB] = a \ + 10 * \gamma * \ log_{10}(d_1)$$

$$L_2[dB] = a \ + 10 * \gamma * \ log_{10}(d_2)$$

Where, a: coefficient for frequency and other propagation factors

γ: is the PLE

d: is distance in meters

Authors in [31] suggested a system framework which is consists of a central server, a base station and four beacon nodes. Its algorithm estimates PLE in dynamically among the beacons and the blind node. Authors also applied the log-distance path loss formula by adding a stochastic component as follow:

$$PL(d) = PL(d_0) - 10\alpha log_{10} \frac{d}{d_0} + X_\sigma$$

Where, PL(d): path loss (db), $PL(d_0)$: is a path loss constant

d: distance in meters, d_0: reference distance α: is the PLE, X_{σ}: account for the long term variability

The exponent (α) is obtained by following formula:

$$\alpha = \frac{-\sum_{i=1}^{n}(PL(d_i) - PL(d_0))}{\sum_{i=1}^{n} 10(log d_i)}$$

Where n is the number of RSSI measurement with a distance d_i

In article [32] proposed a methods based in IEEE 801.15.4 (Zigbee) standard and RSS measurement. In this approach the position of anchor nodes are fixed, clear and also RSS measurement have gathered between pairs of node because they are related to the inter-node distances. By the parametric method the relationship between the RSSI and distance as follows:

$$S = S_0 - \frac{10\ \alpha\ log_{10} d}{d_0} + v$$

Where, S: is value of RSS (dBm) d: is the inter-node distance.

S_0: is the RSSI metrics measured between two nodes d_0 meters apart.

α: represents the power decay index (also known as path loss exponent)

v: is noise typically modeled as a Gaussian random variable $N(0, \sigma_v^2)$ by representing shadow-fading effects in complex multipath environments where the value of standard deviation σ_v depends on the characteristics of the specific environment. The problem solved by computing the location that maximizes the likelihood according to the above model. In other methods, we had same model but the distance across a client and an anchor node is modeled in a linear combination of the RSSI measurements between the client and all the anchors node.

Furthermore, the overall RSSI measurement among all anchor node pairs as an $N \times N$ matrix thus S = [S_1, S_2,…,S_N]. The Euclidean distance for that matrix between anchors is D = [D_1,D_2,…,D_N] which is symmetric and has zero in diagonal. The method for the linear relationship between the RSSI measurements and the logarithm of the inter-node distances as follow:

$$\text{Log (D)} = \text{TS}$$

Where T: is $N \times N$ matrix defining the signal-to-distance mapping. Given the measure between pairs of anchor nodes, the matrix T is derived by means of least squares such as:

$$T = \text{Log}\,(D)S^{T}(SS^{T})^{-1}$$

Finally:

$$\hat{d} = \exp(T\hat{s})$$

Where, $\hat{s}$: is RSSI measurements between client node and its neighboring anchor nodes vector. $\hat{d}$: is distance vector. Lastly a gradient descent algorithm is used to estimate the location based on the obtained distance vector$\hat{d}$.

In matter of moving client nodes the RSSI fluctuations are very high, the accuracy of the system will be very low by using the knowledge of the moving node and also the geometry of the environment which improved localization accuracy by Prediction, Update and Initialization.

Chapter 5: Methodology

5.1: Introduction:

The problem has been depicted in chapter one and various techniques and algorithms which introduced in chapter three in this thesis book. The purpose of this chapter is to introduce, specification and methodological analysis for localization based on problem remarked in chapter one. Generally, finding the location of unknown mobile object or Personal Protective Equipment (Helmet, Shoe and Jacket etc.) what mounted with inertial sensor, microcontroller and transceiver. Its transmit RSSI data and data from accelerometer, gyroscopes and magnetometers is the principal aim of this project.

5.2: Components and Instructions:

All this procedure have constructed with different kinds of components such as:

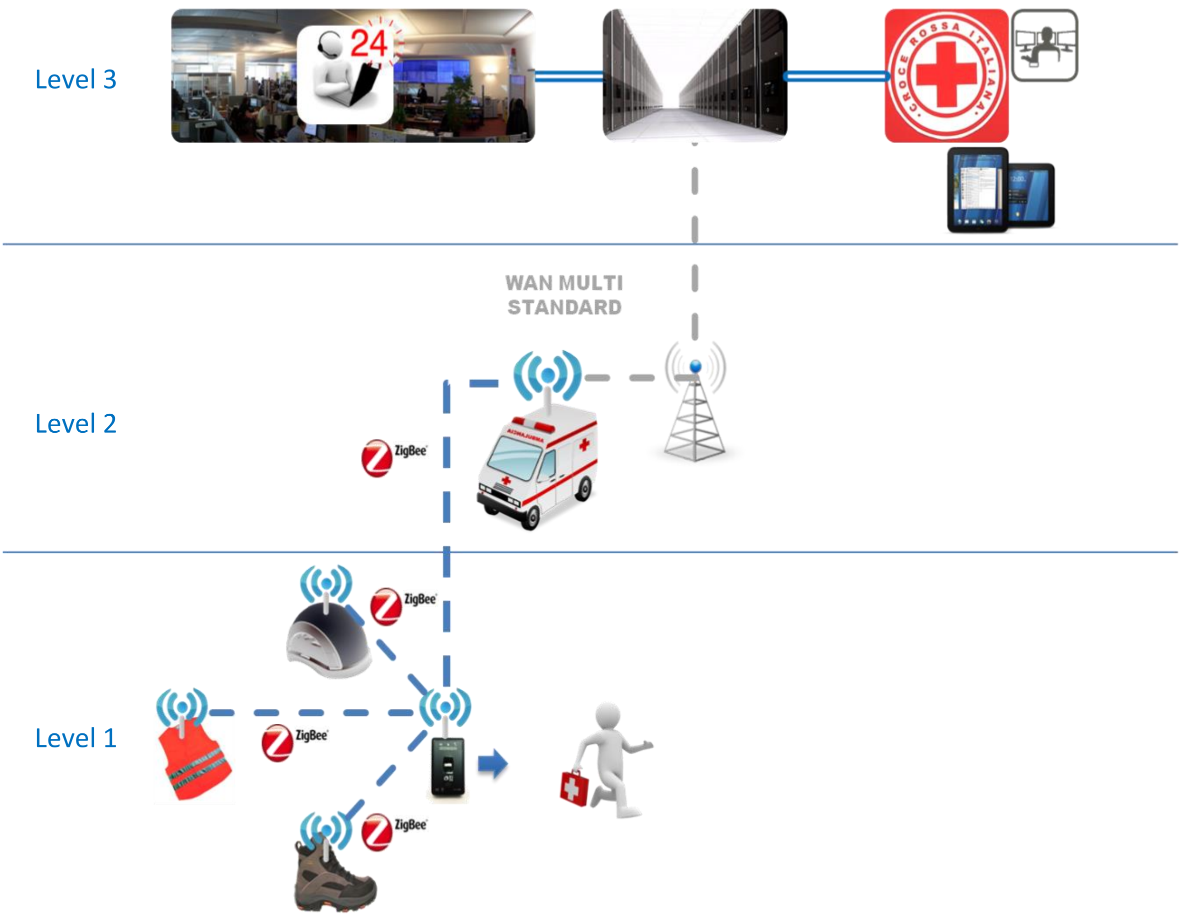


Figure 20: Schematic diagram of Various Components

5.2.1: Mobile Object:

This object is known as unknown beacon node, it's mounted with small microprocessor. Generally it's assimilated and attracts attenuation of other object. Therefore we consider the position of mobile object is known which facilitate unknown object to detect their location. I have observed that in most of the project works and journal beacon node are derived as unknown node. In my project the signal transmitted from this object to the known object while the position of this object are unknown so I called as unknown beacon node.

5.2.2: Sensor:

Its works as both transmitter and receiver which position are known and fixed had to wait until the confirmation of running status of server. Here a microcontroller is functioning as receiver which received transmitted wireless signals and transmits to the server. Its keep waiting to get RSSI signal from mobile object in the meantime High Priority Interruption has been function on the other hand sensor broadcast the packet to master. While there are enough RSSI packets for transferring to the mater then its hold the token and convey time slot postulation to the master. As soon as master received the request its gives an acknowledgement (ACK) for acquiring authorized to send the data. After getting acknowledgement RSSI packet transmit to the master and the communication will be terminated on receiving another acknowledgement. So after next sensor received packet of token from master and transmit this RSSI packet vice versa, this transmit and receive of packet is continuous successive for all sensors.

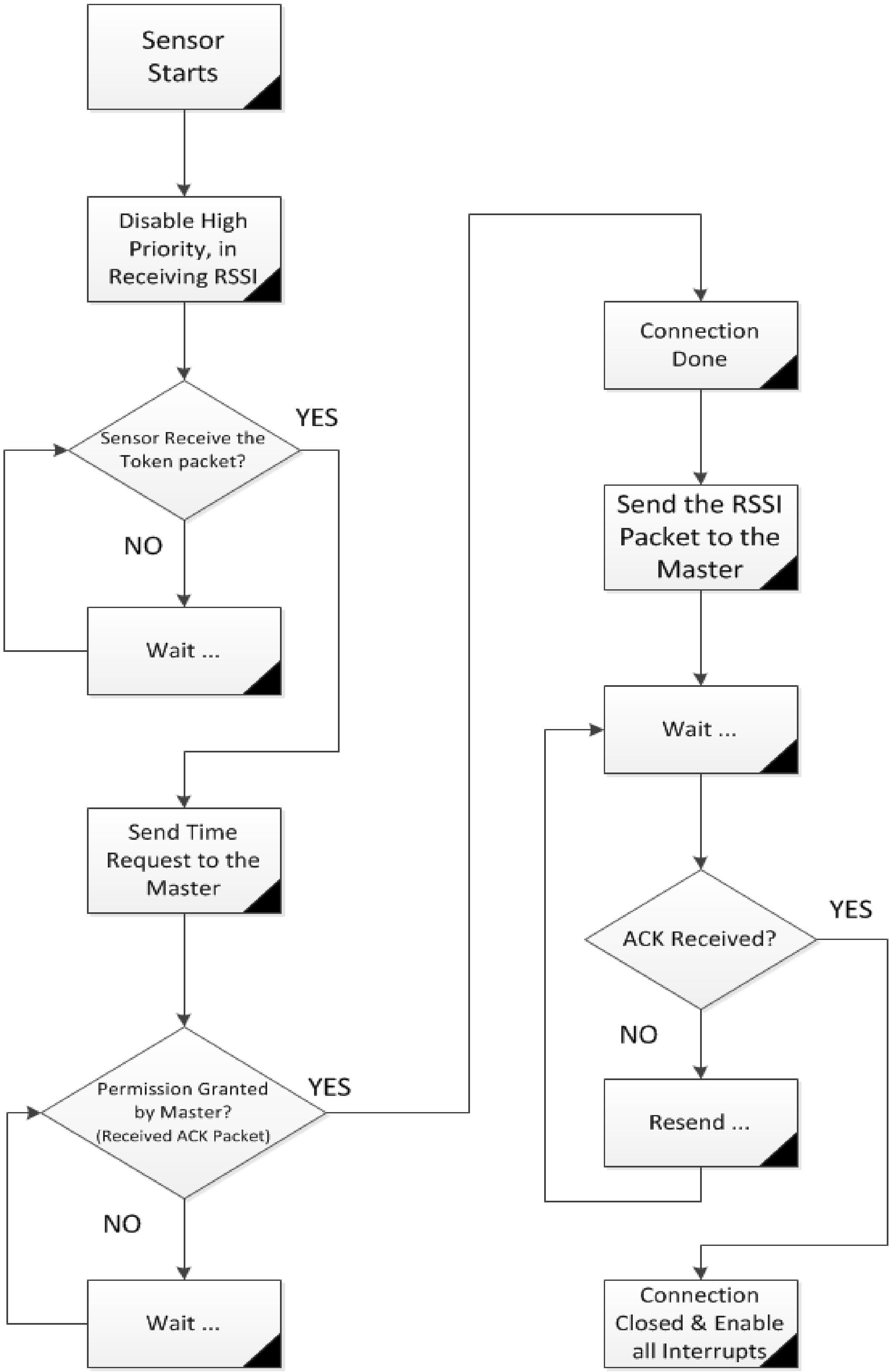


Figure 21: Flowchart of the Sensor Instruction

5.2.3: Path Loss Exponent:

First of all it received RSSI information from sensors around various locations. This value also has impact on average power values. After receiving then it calculate the average and path loss exponent (PL(d)) which is random in an exceptional location among distance. Depending on the environmental barriers the average value may vary. This is an additive pattern for the path loss which is defined as shadowing.

$$PL(d) \quad = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma$$

Here, X_σ: is a Gaussian distribution random variable with zero-mean (dB) and standard deviation σ (dB).

When the Tx-Rx separation is equal for a large number of data has then shadowing effects occurred which is known as log-normal shadowing. The received power can be calculated as follows:

$$P_r(d) = P_r(d_0) - 10n\log(\frac{d}{d_0})$$

Hence the minimum mean square error of path loss exponent as follows:

$$J(n) = \sum_{i=1}^{k}((P_r - \widehat{P}_r))^2$$

Where,

P_r : computed value

$\widehat{P}_r$: Estimated value.

From one of my experiment the measurement data are given below:

#	Distance (meter)	RSSI Rx power(dBm)
1	2.00	120
2	4.00	90
3	6.00	79
4	8.00	61
5	10.00	55
6	12.00	49

Table 3: Calculated values of the experimental test

Harmonizing my experiments with $d_0 = 1\ m$, &$\overline{PL}(d_0) = 130$. The received power for these six (6) positions of mobile object as bellow:

$P_r(d_1)$ = 130 – 10.n.log (1/2) ≈ 130 – 3n

$P_r(d_2)$ = 130 – 10.n.log (4/2) ≈ 130 – 6n

$P_r(d_3)$ = 130 – 10.n.log (6/2) ≈ 130 – 8n

$P_r(d_4)$ = 130 – 10.n.log (8/2) ≈ 130 – 9n

$P_r(d_5)$ = 130 – 10.n.log (10/2) ≈ 130 – 10n

$P_r(d_6)$ = 130 – 10.n.log (12/2) ≈ 130 – 11n

Hence $J(n)$ achieved by summing the square of errors among estimated and assessed values:

$J(n)$ = $(120 – 130 + 3n)^2 + (90 – 130 + 3n)^2 + (79 – 130 + 5n)^2 + (61 – 130 + 6n)^2 +$

$(55 – 130 + 7n)^2 + (49 – 130 + 8n)^2$ ----------- (i)

$= (– 10 + 3n)^2 + (– 40 + 6n)^2 + (– 51 + 8n)^2 + (– 69 + 9n)^2 + (– 75 + 10n)^2 +$

$(–81 + 11n)^2$

→ $J(n) = 414n^2 – 5880n + 21248$

For minimization of the mean square error I have consider of first derivative of $J(n)$ equalize to zero.

Therefore, 828n – 5880 = 0 → n = 7.10 {It's path loss exponent for this measurement}

We can achieve standard division i.e. sigma as bellow:

$\sigma^2 = J(n)$ /6 and $J(n)$ at n = 7.10 can be obtained by putting value of n into equation (i):

$$\sigma^2 = J(n) / 6$$

$$\approx 369.74 / 6$$

$$\approx 61.62$$

$$\rightarrow \sigma \approx 7.85 \text{ dB}$$

5.2.4: Master

Master received the RSSI packets from sensor throughout RS-485 wire from mobile object nodes. After receiving RSSI packets successive its send to the server through RS 232 wire. Its location known by system what established a communication among sensors with server. While master sends token packet to the sensor in the meantime sensor will responded with a request time slot for sending available RSSI packets. As soon as master received ACK packet activate to permit RSSI packet. In the meantime its send ACK packet while RSSI packet has received to accomplish the communication then terminate the communication. By handshaking protocol these packets transmit to the server across RS 232 wire. It's an iterative process.

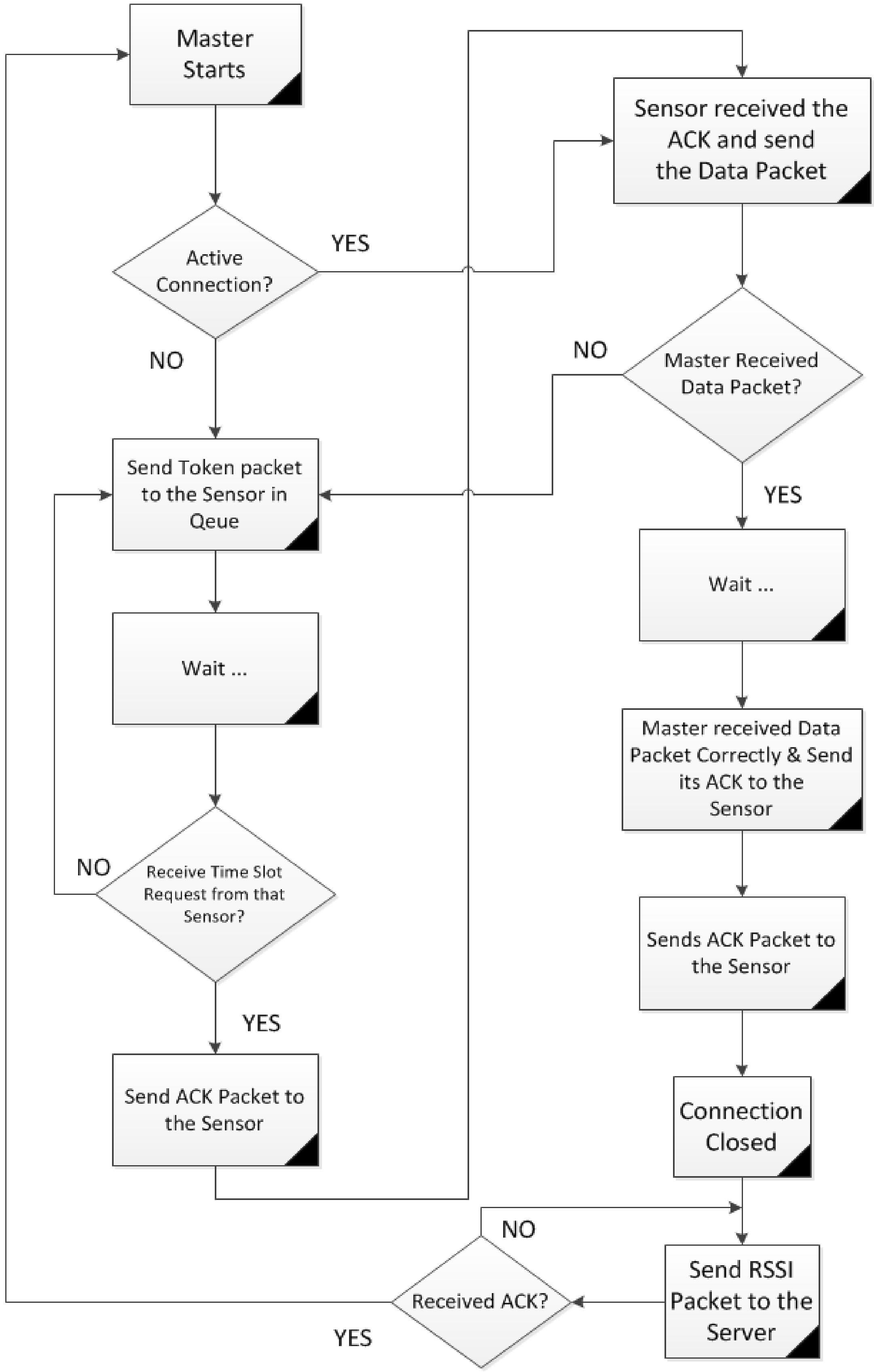


Figure 22: Flow Chart of Master Instruction

5.2.5: Server:

Most of the process execute in the server while its receive RSSI information for localization strategies. For writing localization application I have used C# Visual studio 2008 framework. When the server received RSSI packets from master then some instruction run in the server which has been introduced in another chapter elaborately.

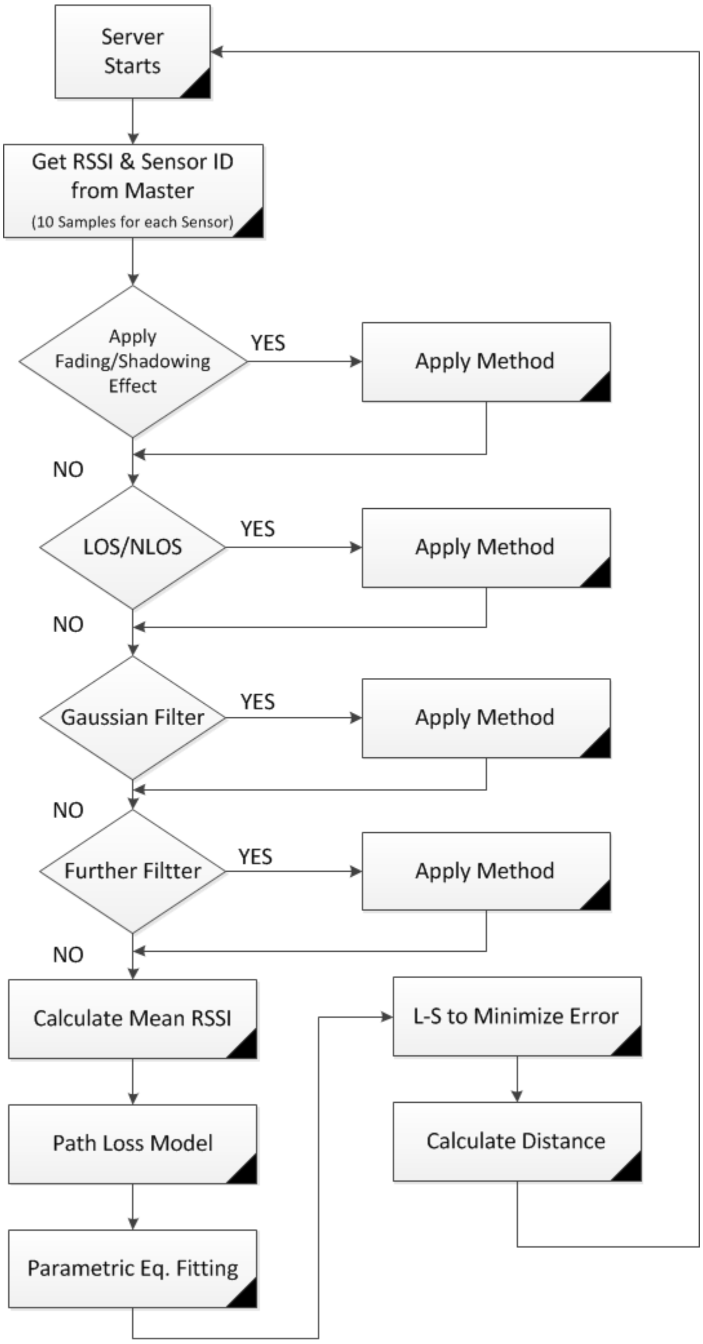


Figure 23: Flowchart of the Server Instruction

5.3: Localization:

During all these discussion I have shown the procedure for receiving and transmitting RSSI information and then its pass through master to master and to the server. Now my focus going to be the procedure server can predict the position of moving object based on the RSSI packets. The localization methodology consists following phases:

a) Receive RSSI packet and optimize it.
b) Measure the Path Loss Exponential for channel LOS/NLOS.
c) Compute Gaussian random variable for every channel towards fading and shadow effects.
d) Compute linear system parameter estimation.
e) Channel recognition by using probability density function.
f) Measure the distance for particular channel.
g) Fitting polynomial curve for error minimization

$$F(\log\ (error)) = A(RSSI)^3 + B(RSSI)^2 + C(RSSI) + D \text{ -----(ii)}$$

I have estimated these parameters using known distance and Least Square with different phase.

5.3.1: Received Signal Strength:

The estimation of Received Signal Strength using statistical mean and Gaussian filer according to the distance among the sensors is usually used. Sensor occupies with known location and received every packet transmitted by moving object. After receiving the packet the sensor measures signal strength of the packet. The RSSI information for the moving object with ID sends. In my experiment RSSI value differ depending on environment in time by time, there were different sources of interfere, precarious factors what may have touch on the propagation of signal. First we should optimized the RSSI values since measurement of the distance are not precise. Usually to optimize the RSSI value the average statistical and Gaussian model used taking consideration the distance between the fixed nodes. By using Gaussian model we can select the value of high probability area than average statistical model. Use of Gaussian models its increase the precision of the location. Therefore, I have introduced a Gaussian filter for the set of received RSSI information. This filter also decreases noise into the RSSI sample set.

The Gaussian filter derived as:

$$u = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - m)^2$$

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-u)^2}{2\sigma^2}}$$

For this project I have set a threshold from 0.6 to 1.0:

For every RSSI sample into the Set

gRSSI = GaussianFilter();

if(gRSSI >0.6 and gRSSI <1.0)

stackRSSI ← gRSSI

Now a new sample set will be generated by taking comparisons in the inequality and statistical mean has been measured. These mean value will be use into the second step for the localization.

5.3.2: Path Loss Exponential:

The relationship between transmitted power and received power of wireless signals is as follows:

$$P_r = P_t \times (\frac{1}{d})^n$$

Where, P_r : the receive power of wireless signals.

P_t : The transmitted power of wireless signal.

d : the distance across the sending nodes and receiving nodes n : the transmission factor which is depends on the propagation environment.

Recently free-space, ground bidirectional reflectance and log-normal shadow model has been introduced in wireless sensor network.

We can use free-space model in following scenario:

1) When transmission distance is very higher than the antenna size and also carrier wavelength λ

2) Also in absence of obstacles between the transmitters and the receivers.

For example, the transmission power determined by following conventions:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

$$PL(dB) = 10 \log \frac{P_t}{P_r} = -10 \log[\frac{\lambda^2}{(4\pi)^2 d^2}]$$

Where,

G_t , G_r : antenna gain,

L: is system loss factor

We can use surface bidirectional reflectance model is applicable to the following scenario: 1) transmission distance d within few kilometers.

2) The height of antenna of transmitter and receiver which is equal or greater than 50 meters.

The received power measured by the following equation:

$$P_r(dB) = P_t . G_t . G_r \frac{{h_t}^2 {h_r}^2}{d^4}$$

$$PL(dB) = 40. \log d - (10. \log G_t + 10.\ \log G_r + 20. \log h_t + 20\,. \log h_r)$$

Where, $h_{t:}$ height of sending antenna.
h_r: height of receiving antenna.

Log-normal shadow model is worthy for both indoor, outdoor environments. To measure we can derived the formula as below:

$$PL(d) = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10\beta \log\left(\frac{d}{d_0}\right) + X_\sigma$$

Where, d_0 : the near-earth reference distance,

β : path loss index, its depends on propagation environment,

X_σ : Gaussian random variable with zero-mean.

This model is useful for designing and analysis of general wireless systems. Its general propagation model, It's essential to adapt $\overline{PL}(d_0)$, β and X_σ in the model depending onto specific environment.

5.3.3: Gaussian Random Variable:

In Log-distance model is not taking into account the existence of immensely differ positions while the same situation for Tx-Rx based on different surrounding environment. Therefore there are high varieties on measured signals from the estimated average values with path loss model. For solving such kind of limitation real value considered as random and distributed Log-normal in dB:

$$PL(d) = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10\beta \log\left(\frac{d}{d_0}\right) + X_\sigma \quad (1) \text{ PL (d) in dB}$$

X_σ: Gaussian Random Variable with zero-mean with standard deviation σ in dB

Where, X_σ describes the shadowing effect which take place throughout different measured signal strength at position with equal Tx-Rx separation. Therefore, after considering the gain of antenna admitted in PL(d) we get:

$$P_r(d) = P_t - PL(d) \qquad P_r \text{ and } P_t \text{ in dBm}$$

For the probability that the received signal level which outgo particular level if PL (d) is a normally distributed RV, we can get following equation:

$$Q(z) = \frac{1}{\sqrt{2\pi}} \int_z^\infty e^{-\frac{x^2}{2}} dx = \frac{1}{2}[1 - \text{erf}\left(\frac{z}{\sqrt{2}}\right)]$$

To exceed the value γ for received signal the probability is (in dB):

$$\Pr[P_r(d) > \gamma] = Q(\frac{\gamma - \overline{P_r}(d)}{\sigma})$$

To fall down the value of γ for received signal the probability is (in dB):

$$\Pr[P_r(d) < \gamma] = Q(\frac{\overline{P_r}(d) - \gamma}{\sigma})$$

In initial step the measured value used to compute the value γ by using that the effect of shadowing decreased in real time condition. We can see different parameter for this model which can derive according to environmental condition.

The log-normal probability density function is:

$$f_{LN}(x) = \frac{1}{\sqrt{2\pi}\sigma x} \exp(\frac{-(\ln x - \mu)^2}{2\sigma^2})$$

μ: The mean received signal strength σ: Standard deviation

From my experiment experience on some signal strength group (d, RSSI) following function can be depicted for the variance and distance:

$$\sigma(d) = Ad^3 + Bd^2 + Cd + e \quad (2)$$

Here, A, B, C and e are undetermined coefficients. The values are dynamically adjusted based on different environments.

By putting the equation (2) into equation (1) we have:

$$PL(d)(dB) = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10\beta \log\left(\frac{d}{d_0}\right) + \sigma(d)X$$

Log-normal shadowing model is able to dynamically control the error function because of the function $\sigma(d)$ with difference distances.

5.3.4: Estimation of Empirical Distance:

Its gives linear equation while path loss is calculated in dB. The equation is as follows: R = Kd + S, where r: the output here is taken as Received Signal Strength. K: the system parameter, S: noise. The distance d and RSSI/ R are known which can demonstrate an acceptable linear equation. In the calibration step every linear equation has demonstrate for every sample point during this step parameter K, S is measured by Least Square method. This linear system measured the distance by RSSI is derived as empirical distance. This distance is used in channel identification to calculate probability density function.

5.3.5: Identification of Channel:

A channel may define as Line of Sight and Non-Line of sight depending on the location of the transmitter and receiver antenna. This phase are related to find out the receive data source from Line of Sight or Non-Line of Sight. Non-line of Sight propagation may badly take down reliability of localization and communication accuracy. Non-Line of Sight identification technique established on hypothesis testing for received signal parameters.

The NLOS identification problem expression can be elaborated as followings: For finding the state H of the channel among the transmitter and receiver nodes is separated physically. This state are separated by a distance d and estimation of RSS observed in the receive node.

Hence, H = H0 represents to LOS propagation, H = H1 represents to NLOS propagation. By localization point of view the soft NLOS events relegated as LOS scenarios since the LOS multi path element can measure for ranging purposes. The range estimates does not essentially biased in soft NLOS propagation environments.

The normalized RSS (in dB) is defined as follows:

$$S_{dB} = 10 \log_{10}(\frac{1}{P_0 T} \int_T |r(\tau)|^2 d\tau)$$

Where, P_0: the received power with reference distance d_0, T: the measurement interval for the received signal. The estimated RSS modeled as log-normal random variable since absence of important multipath fading.

$$\hat{S}_{dB} = 10.\beta \,.\log_{10}(\frac{d}{d_0}) + X$$

Here, β: the path loss exponent, X: Gaussian random variable with zero-mean along with dissimilar variances in LOS and NLOS.

$$f_X(x) = \begin{cases} (2\pi.\sigma_{SL}^2)^{-\frac{1}{2}} \exp\left(-\frac{x^2}{2\sigma_{SL}^2}\right), & H = H_0 \\ (2\pi.\sigma_{SN}^2)^{-\frac{1}{2}} \exp\left(-\frac{x^2}{2\sigma_{SN}^2}\right), & H = H_1 \end{cases}$$

The conditional density functions of $\hat{S}_{dB}$ can be represented as follows:

$$f_{\hat{S}_{dB}}(S|d,H) = \begin{cases} (2\pi\sigma_{SL}^2)^{-\frac{1}{2}} \exp\left(-\frac{(S - 10\beta_L \log_{10} d)^2}{2\sigma_{SL}^2}\right), & H = H_0 \\ (2\pi\sigma_{SN}^2)^{-\frac{1}{2}} \exp\left(-\frac{(S - 10\beta_L \log_{10} d)^2}{2\sigma_{SN}^2}\right), & H = H_1 \end{cases}$$

By the value of likelihood the state of the channel can identified for each of the estimates x_i. Also we need to set the condition on the distance d for both H =H_0 and H = H_1.

5.3.6: Find Distance for a particular Channel:

The likelihood that estimation happened since NLOS propagation is higher instead of LOS propagation while d is known. The maximum likelihood (ML) channel state would be $\hat{H} = H_1$, directly can be obtained from the known conditional distributions. Usually we do not know the physical distance d between the nodes. Therefore it's very necessary to estimate the distance d perfectly for localization applications. To estimate the linear system model parameter we have been used empirical distance estimation by fitting a linear model.The joint channel state identification is defined as follows: Initial hypothesis is the state of the channel is LOS i.e. $\hat{H} = H_0$.Also d is estimated from the linear model. For each estimate is necessary to determine the conditional probabilities:

$$p_i = Pr\{X_i = x_i|\hat{d}, H_0\}; \qquad q_i = Pr\{X_i = x_i|\hat{d}, H_1\}$$

Now I have to compute $D_L = \prod_i p_i$ and $D_N = \prod_i q_i$. It should be mentioned that if the estimates are performed for a fixed distance and channel state. The D_L and D_N are joint conditional probabilities for the estimates. The values of D_L and D_N can function as the decision metrics to estimate the state of channel.

$$\hat{H} = \begin{cases} H_0, & D_L > D_N \\ H_1, & D_L < D_N \end{cases}$$

5.3.7: Estimation of the route of Crew's:

The applicability and the performance of the Inertial Measurement Unit (IMU) for a crew tracking application, the route is estimated while jacket or shoes were fitted with an IMU. In approached to estimate the position of a crew based on inertial sensors is directly integration according to [50]. Considering the navigation equations in the gyroscope to achieved the orientation data which transfer the sensor coordinate to the global coordinate system. As soon as the coordinate transformation we can get acceleration data, velocity and the location by integration across time. In [47] authors give brief description on the navigation equation. Because of sensor drift the estimated orientation have affect from accumulating errors. Here I have utilized sensor data fusion based on modified filters which improve the accuracy of the estimated orientation [49].

The structure of the system as follows:

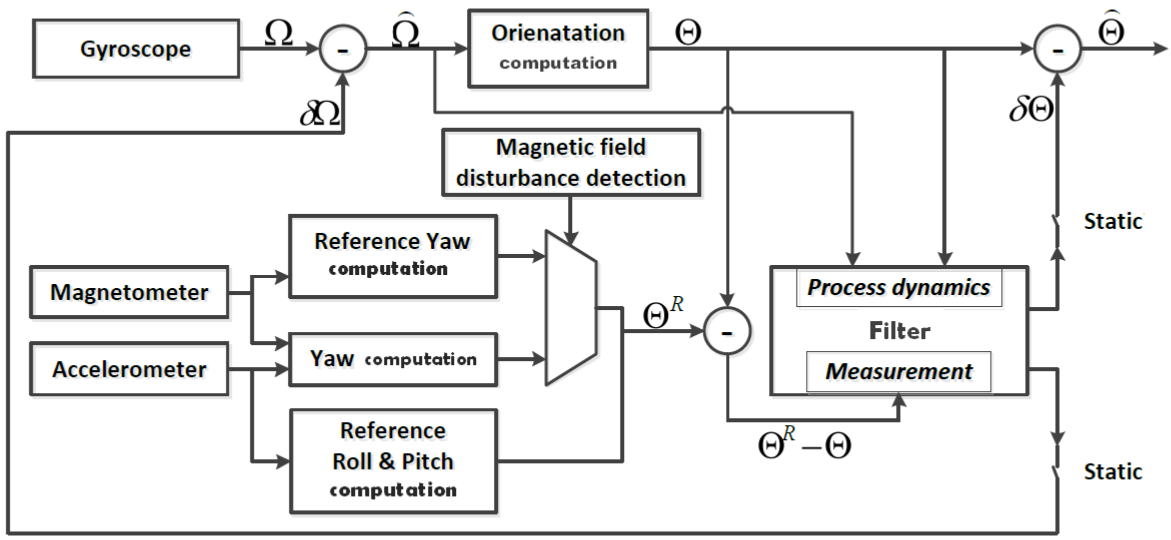


Figure 24: Block diagram of filter structure.

I model the system state like the orientation error δΘ and the angular rate errorδΩ. I have considered the difference among the gyro-based and the magnetic field or acceleration based orientation. It was possible to keep away from non-linear system function. By subtracting the bias error δΩ from the filter based sensor data fusion the angular rate data Ω is adjusted. To compute the gyro-based orientation Θ from the corrected angular rate $\hat{\Omega}$ I have used navigation equation and Quaternion algebra.

For obtaining another set of orientation data Θ^R combined the three-axis magnetometer and accelerometer data. Hence when the acceleration data is static then the reference orientation can measure. That is the norm of the acceleration data which is almost closer to the gravity. The diversion $\Theta^R - \Theta$ among the reference orientation and the orientation estimate of the gyroscope is used as filter measurement. By using Quaternion algebra the corrected orientation $\widehat{\Theta}$ is achieved with subtracting $\delta\Theta$ fromΘ. When the acceleration data is not static then $\widehat{\Theta} = \Theta$ and $\widehat{\Omega} = \Omega$ which means the incorrect Θ^R has no affected on the resulted$\widehat{\Theta}$. Usually we may get incorrect reference orientation Θ^R while the magnetic field measurements are affected by local disturbances.

By processing the magnetic field and acceleration measurement data the magnetic disturbances can be detected. An alternative magnetic field vector generated for calculating the reference orientation then the impact of disturbances are minimized.

Recursively the position is measured by integrating the acceleration data across time. Filter be effected with an accumulating errors the translation velocity and in the estimated location. To deal with this error the “Zero Velocity Update” (ZUPT) method [48] has been used. In the case of normal walk of crews the still phase is experienced. As soon as still phase is detected is needed to reset the velocity value. By experiment the gyroscope data the state of the still phase is best estimated. In the case of norm for the angular rate measurement Ω of the gyroscope is smaller than a threshold then we can derived that the crews is in the still phase and also the velocity can be readjust.

Chapter 6: Hardware and Firmware

6.1: Introduction:

The communication architecture among moving object, sensors mounted on Personal Protective Equipment (PPE) and Master with control unit. To developed methodology I have used Microcontroller, Concentrator and Sensor with distinct firmware.

6.2: Hardware:

The architecture as a whole consists of a three-tier network.

The first level consists of data from sensors mounted on PPE, which are transmitted to the control unit through the middle (second level), to the platform control panel (third level), making them immediately available to service center operators and managers of emergency management.

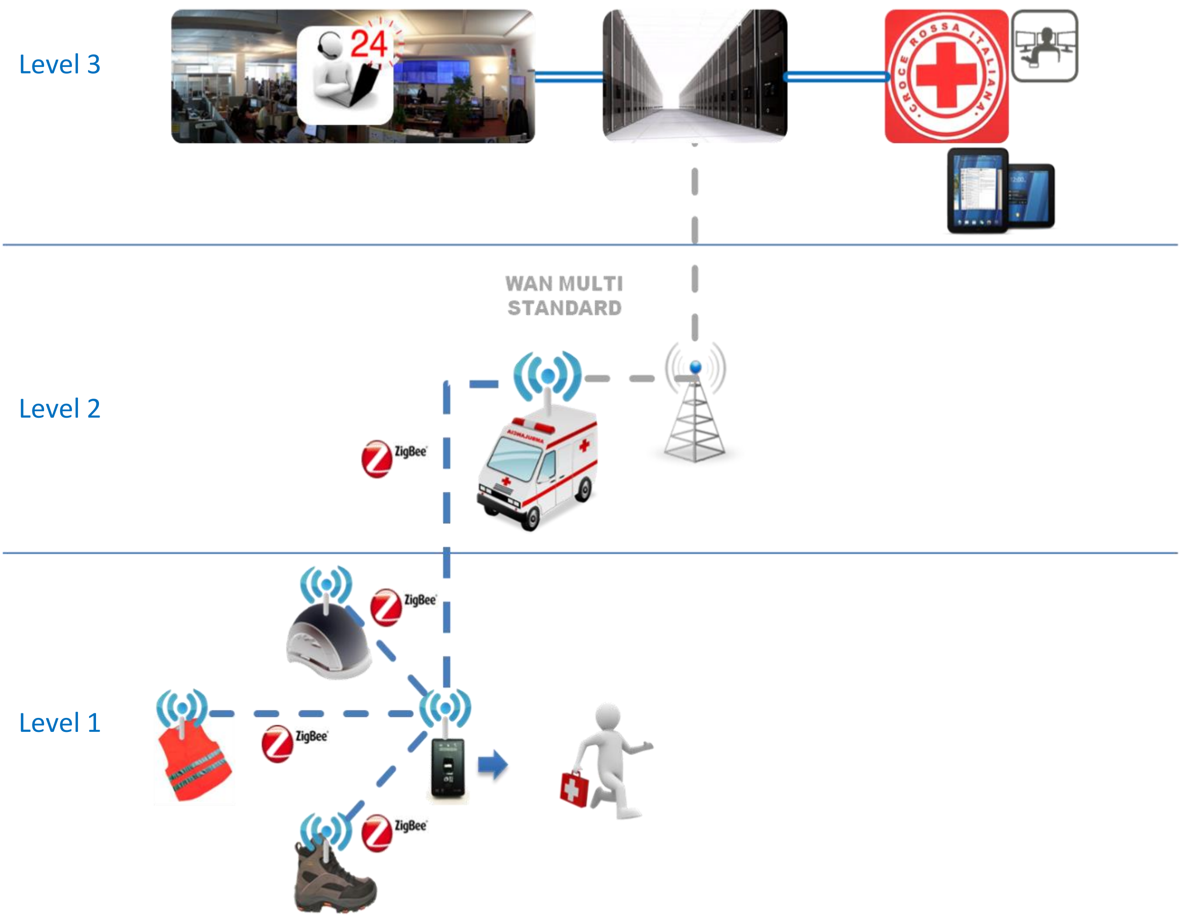


Figure 25: Architectural view of SR system

The system is configured so that the sensors, typically of one of the shoes, are associated with the data of the rescuer, for which the intervention is fully monitored and historical context with evidence of situations and demographic information and expertise of the participants.

In complex emergencies where it may happen that the rescuer needs more than 150 meters away from the middle, a hardware bridge will allow to raise the signal, while maintaining control and continuous contact during an emergency

Figure 26: Image of DPI Device

At each control unit on the rescue vehicle other modules are connected to control and unifying information related to:

- Rescue vehicle, allowing you to track the position of moving vehicles in real-time by posting the positions at the operations center.
- Functionality of the instruments and equipment installed on the vehicle (the defibrillator, oxygen, ECG, pressure), alerting in case of malfunctioning.

Note that it is possible to transmit a position on the second and for the security system installed on the vehicle is equipped with backup batteries.

There are following configurations:

- ✓ Moving Object to Sensors
- ✓ Moving Object to Path Loss Exponent Node
- ✓ Sensors to Master and vice versa
- ✓ Master to the Server and vice versa

I have used concentrator with microcontroller which is high performance from microchip products and integrated ISM band sub GHz transceiver.

6.2.1: Microcontroller:

For my project I have used PIC18F47J13 microcontroller with Nano technology. The power management characteristics with Nano watt xlp for low power we can derive as follows:

- ✓ Deep Sleep mode: CPU Off, Peripherals Off, SRAM Off which is able to wake-up on external triggers and ultra-low-power wake up.
- ✓ Sleep mode: CPU Off, Peripherals Off, SRAM On, and Fast Wake-up.
- ✓ Idle: CPU Off, SRAM On, Currents fall Down to 1.7 µA distinctive.
- ✓ Run: CPU On, SRAM On, Currents fall Down to 5.8 µA distinctive.

Features	PIC18F46J13	PIC18F47J13
Operating Frequency	DC – 48 MHz	DC – 48 MHz
Program Memory	64Kb	128Kb
Program Memory	32,768 Instructions	65,536 Instructions
Data Memory	3.8 Kb	
Interrupt Sources	30	
I/O Ports	Ports A, B, C, D, E	
Timers	8	
Enhanced Capture or Compare or PWM Modules	3 ECCP & 7 CCP	
Serial Communications	MSSP (2) and Enhanced USART (2)	
Parallel Communications (PMP or PSP)	Yes	
10 or 12-Bit Analog-to-Digital Module	13 Input Channels	
Resets (& Delays)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow, MCLR, WDT	

Instruction Set	75 Instructions, 83 with Extended Instruction Set Enabled

Table 4: PIC18F4XJ13 Features

This microcontroller has some peripheral such as Hardware Real Time Clock or Calendar, Four programmable external and input changes interrupts. It has also 8-bit parallel master port or enhanced parallel slave port and enhanced USART modules. For this microcontroller some other special features such as 5.5V tolerant input for digital, C compiler optimized architecture and priority levels for interrupts.

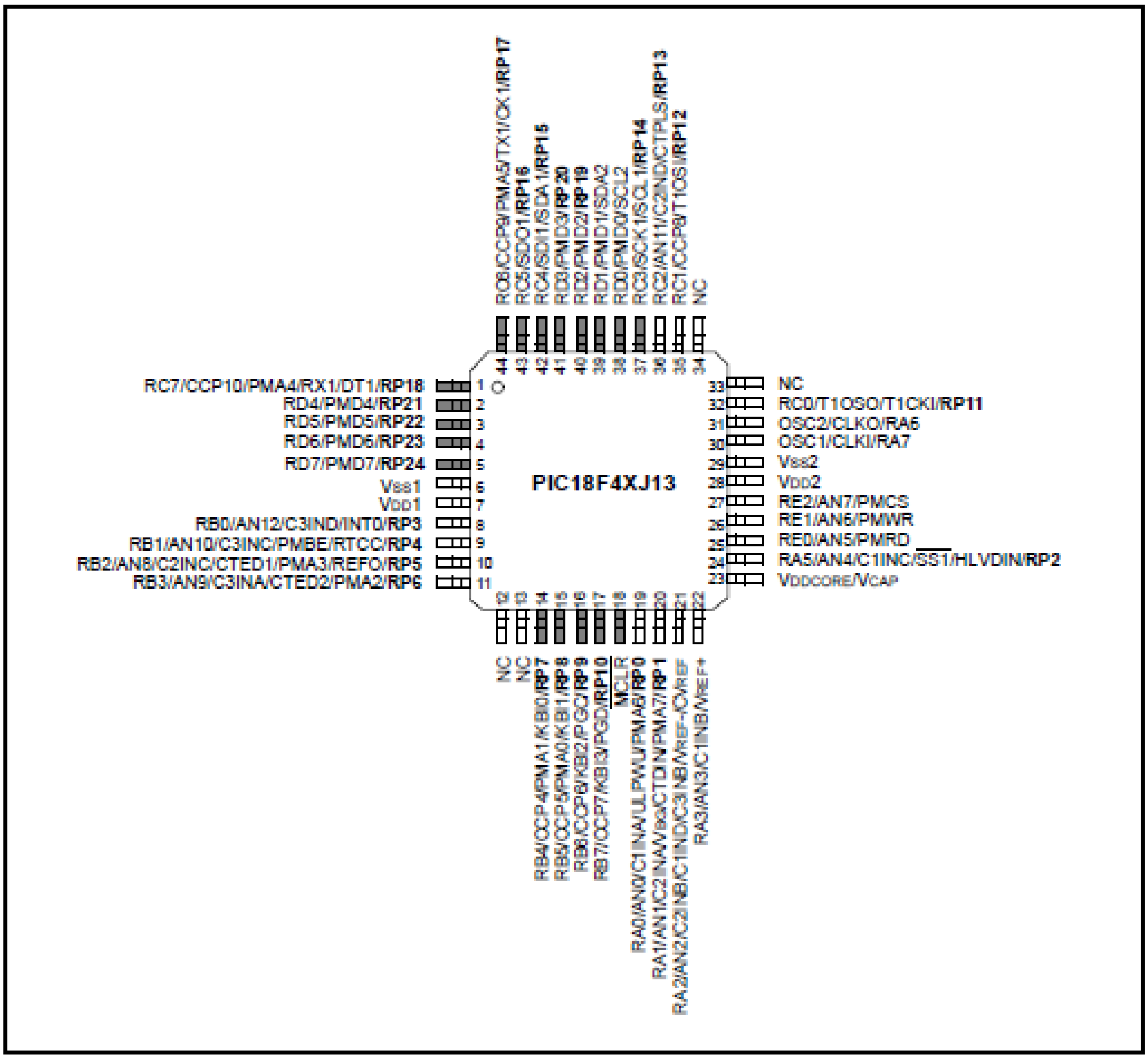


Figure 27: Pin configuration for PIC18F4XJ13

6.2.2: Transceiver

As a transceiver I have chosen MRF89XA which is ultra-low power integrated ISM band. Its supports wireless protocols along with wide band half duplex transceiver. .

- ✓ Operating voltage: 2.1V-3.6V
- ✓ Low-current consumption, typically: 3 mA in RX mode and 25 mA +10 dBm in TX mode. Also 0.1 μA and 2 μA in sleep mode.

The radio frequency, analog features supports ISM band sub-GHz frequency ranges 863-870, 902-928 and 950-960.In my project I have used 870 MHz's. It is reception sensitivity fall down to -107 dBm in 25 kbps. Its reception sensitivity is -113 dBm at 2 kbps. RF output power is +12.5 dBm programmable. Its wide received signal strength indicator (RSSI) dynamic range is 70 dB from Rx noise floor. Other features as follows:

- ✓ Signal-ended RF input/output and On-chip frequency synthesizer
- ✓ Supports PLL loop filter with lock detect
- ✓ Integrated Power Amplifier and Low Noise Amplifiers
- ✓ Channel filters and On-chip IF gain and mixers
- ✓ Integrated low-phase noise VCO

This transceiver has 64 byte transmit or receive Fast In Fast Out in stand-by mode. Its low cost transceiver which optimized for very low power consumption too. And it is 3 mA in receiver mode. Usually this module has several application as like home, industrial automation system, wireless sensor networks, Intelligent safety and security system, vehicle sensor monitoring system and also for medical application.

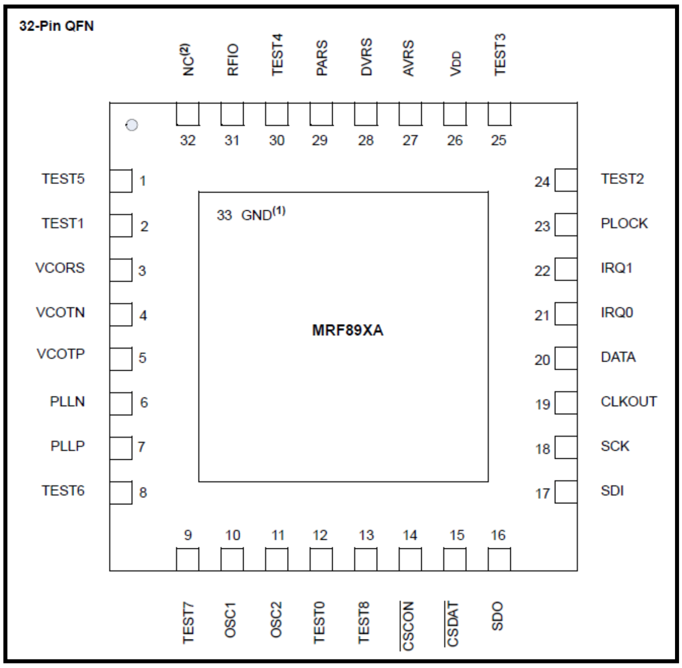


Figure 28: Pin Configuration of MRF89XA

The MRF89XA corroborates the Received Signal Strength Indicator (RSSI), sync word recognition. It also support 64-byte Tx-Rx FIFO, packet handling, buffer and packet, data filtering, whitening filtering and encoding and also base band power amplifier.

In my project I have used such kind of module to interfacing the data between the microcontroller access points and controls the entire configuration registers.

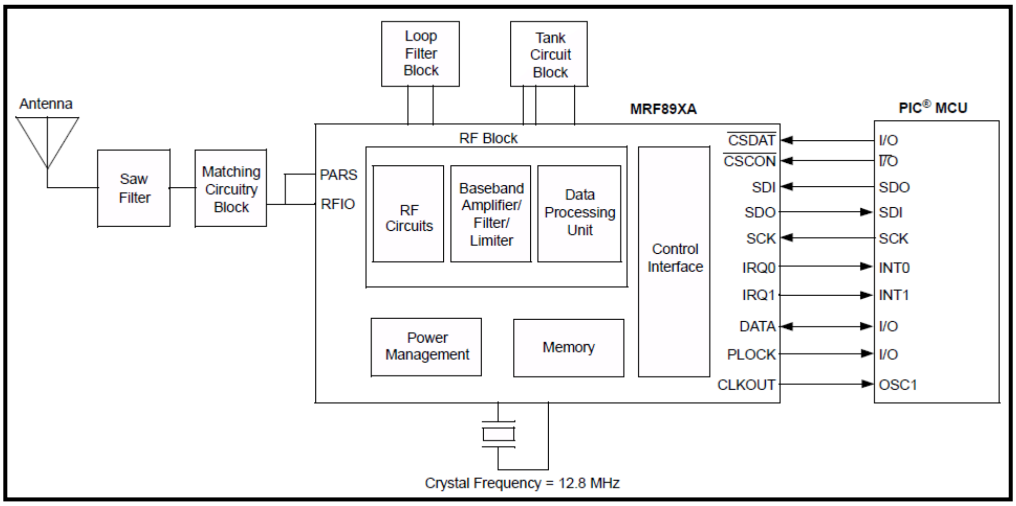


Figure 29: Interface between MRF89XA and Microcontroller

6.2.3: Concentrator:

I have used PIC18F47J13 microcontroller and MRF89XA transceiver mounted as a concentrator. In my project using different programs it's acted as Moving Object, PLE Node, Sensors and Master.

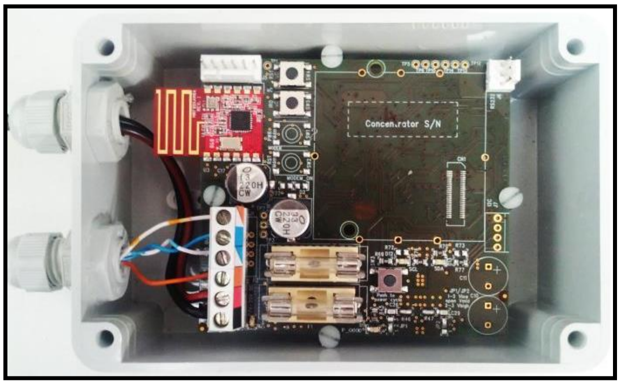


Figure 30: Concentrator

It has three different layers of protocol:

- ✓ Physical Layer
- ✓ MAC Layer
- ✓ Application Layer

In my methodology master node can send token packet to all sensors iteratively.

Block	Position	Field length	Field meaning
Protocol	1	1	STX
	2	1	Packet Counter (Numerator)
	3	1	Packet Total (Denominator)
	4	1	Type
Error status	5	1	Last Sensor – Concentrator communication error
	6	1	Sensor – Concentrator communication failures
	7	1	Last Concentrator – Gateway communication error
	8	1	Concentrator – Gateway communication failures
	9	4	Error Flags

	10		
	11		
	12		
Serial numbers	13	4	Sensors or Master
	14		
	15		
	16		
	17	4	Sensor SN
	18		
	19		
	20		
Measurement data	21	4	Data 1
	22		
	23		
	24		
	25	4	Data 2
	26		
	27		
	28		
	29	4	Data 3
	30		
	31		
	32		
	33	4	Data 4
	34		
	35		
	36		
	37	4	Future Data 1

	38		
	39		
	40		
	41	4	Future Data 2
	42		
	43		
	44		
	45	4	Future Data 3
	46		
	47		
	48		
	49	2	Sensor Temperature
	50		
Radio channel details	51	1	RF Band
	52	1	RF Channel
	53	2	RF Measures
	54		
HW/FW revisions	55	1	Future service info
	56	1	Future service info
	57	1	Concentrator FW Version
	58	1	Concentrator HW Version
	59	1	Sensor FW Version
	60	1	Sensor HW Version
Protocol	61	2	Sensor measure counter
	62		
	63	2	Checksum
	64		

Table 5: Description of Packet

The significant packets are possible to send from sensors or master to another one is:

- ✓ Radio Network Reset Packet: 0xE0
- ✓ Sync Packet: 0xE1
- ✓ ACK Packet: 0xE3
- ✓ Data Request Packet: 0x01
- ✓ Intro Packet: 0xE2
- ✓ Data Packet: 0x10

The token packet can be a data request packet from master to the sensor. Therefore all sensors received that packet. The packet with serial number of packet put into packet track after that it's continue sending RSSI packet. Furthermore the sensor sends intro packet to the master for showing that RSSI packet is present. Then it transfers to the master. On the other hand in absence of RSSI packet could not send intro packet. The master node wait until certain period of time then it sends next token packet to next sensor. As soon as ACK packet from master to the sensor are send. The sensor by transmitting the data packet transfers the RSSI packet to the master. Finally master sends the ACK packet to the sensor once more after that closed the communication.

In my project work I have used some sensors in bus topology. It's simplest way to connect them. Also there will not be any collision problem because of token packet method.

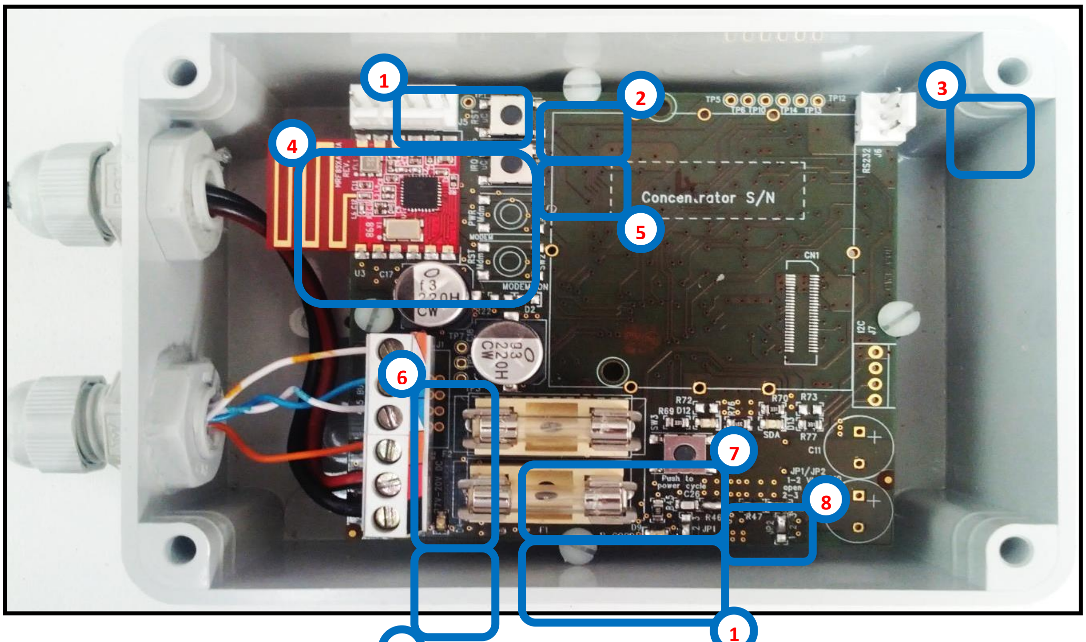


Figure 31: Concentrator board

The Concentrator consists with following parts as bellow:

1. Microcontroller Programming Port
2. Microcontroller Reset Button
3. RS-232 Interface Port
4. Wireless Module
5. Concentrator Configuration Button
6. RS-485 Interface Port for Communication to the Sensors
7. Sensor Power Rail Protection Fuse
8. Power Cycle Button
9. Power Cord Connector
10. Master Power Protection Fuse

6.2.4: Inertial Sensor:

I have used Inertial Measurement Units for estimating the crew's position and displacement which is provide the inertial data. It's a commercially available IMU model MTi from Xsens Technologies B.V. (www.xsens.com). Its size is 58 X 58 X 22 mm (length X width X height) and also weight 50 g.

The IMU consisting of a three orthogonally oriented accelerometers, three gyroscopes and three magnetometers. Theoretically a calibrated IMU used to measure 3D angular velocity and three dimensional acceleration and gravity according to the sensor housing. For given initial position and orientation, generally such signals would contain enough information to generalize the IMU kinematic wholly. The orientation can be achieved by using a known initial orientation. Also the change in orientation can be achieved by using gyroscopes. For subtracting the gravity from 3D accelerometer vector to the yield acceleration the obtained orientation are used.

Furthermore, the acceleration can be achieved by considering the low-frequency part of the signals by enabling the measurement of 3D acceleration and 3D angular velocity using a sensor based. Also it has been shown experimentally for an angular velocity across a single axis. By constructing such a sensor will have big advantages across a sensor comprising three single axis accelerometers and three single axis gyroscopes with respect of size and power consumption.

Figure 32: Image of IMU

Its accelerometers and gyroscopes are solid state MEMS with capacitive readout by supplying linear acceleration and rate of turn respectively. For measuring the earth's magnetic field magnetometer used a thin-film magneto resistive. Individual MEMS sensors with MTi IMU the performance are derived in following table (Xsens specifications). They may suffer from a significant bias what varies over time i.e. bias stability. In my project I have used the IMU equipped on the shoe of crew for taking advantage of ZUPTs.

	Accelerometers	**Gyroscopes**	**Magnetometers**
Axes	3	3	3
Full Scale (FS)	$\pm 50\ m/S^2$	$\pm 300\ deg/S$	$\pm 750\ mGauss$
Linearity	0.2% of FS	0.1% of FS	0.1% of FS
Bias stability	$0.02\ m/S^2$	1 deg/s	0.1 mGauss
Bandwidth	30 Hz	40 Hz	10 Hz
Max update rate	512 Hz	512 Hz	512 Hz

Table 6: Performance of individual sensors in Xsens IMU

6.3: Firmware:

For programing the modules I have used the MPLAB IDE V.8.86 from Microchip which uses Microchip C18. Also for programing the concentrator I have used the MPLAB ICD2 programmer.

Figure 33: MPLAB ICD

6.3.1: MPLAB IDE:

MPLAB Integrated Development Environment is a software program for developing application for microcontrollers. To write, edit, debug and program which are the intelligence of embedded system applications. In microcontroller a system development is essential for embedded controllers. The procedure for developing an embedded controller application is as follows:

1. Creating the high level design
2. Compiling
3. Testing the Code
4. Burning the code into the microcontroller

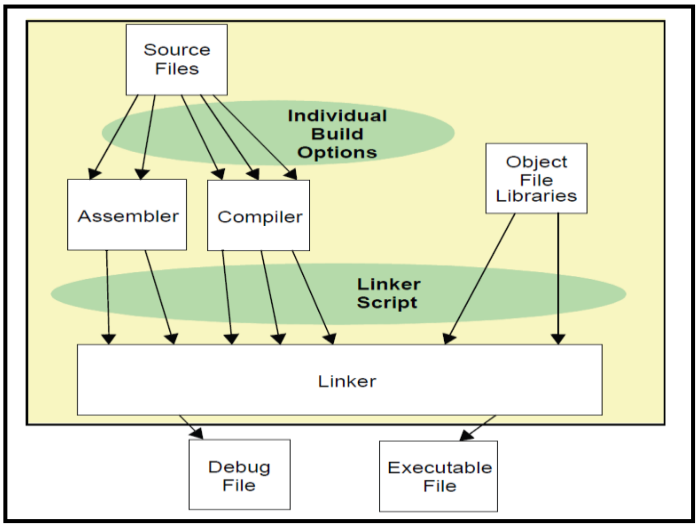


Figure 34: Project Manager of MPLAB IDE

6.3.2: Complier:

Here the MPLAB C18 C is software tools have used for embedded system programming. It examines the functions and difference between compliers and assemblers. Its represents programmers with executable and execution flow. The cross-complier generated code which can be run by microchip PIC18xxxx series microcontroller. Such as all assemblers C18 is an interface between human and systems. The MPLAB C18 takes standard C code for converting them into PIC18xxxx machine code. This complier developed of embedded systems applications more comfortable by using the C standard language. The generated code of this language is extremely suitable for the PIC18xxxx microcontrollers.

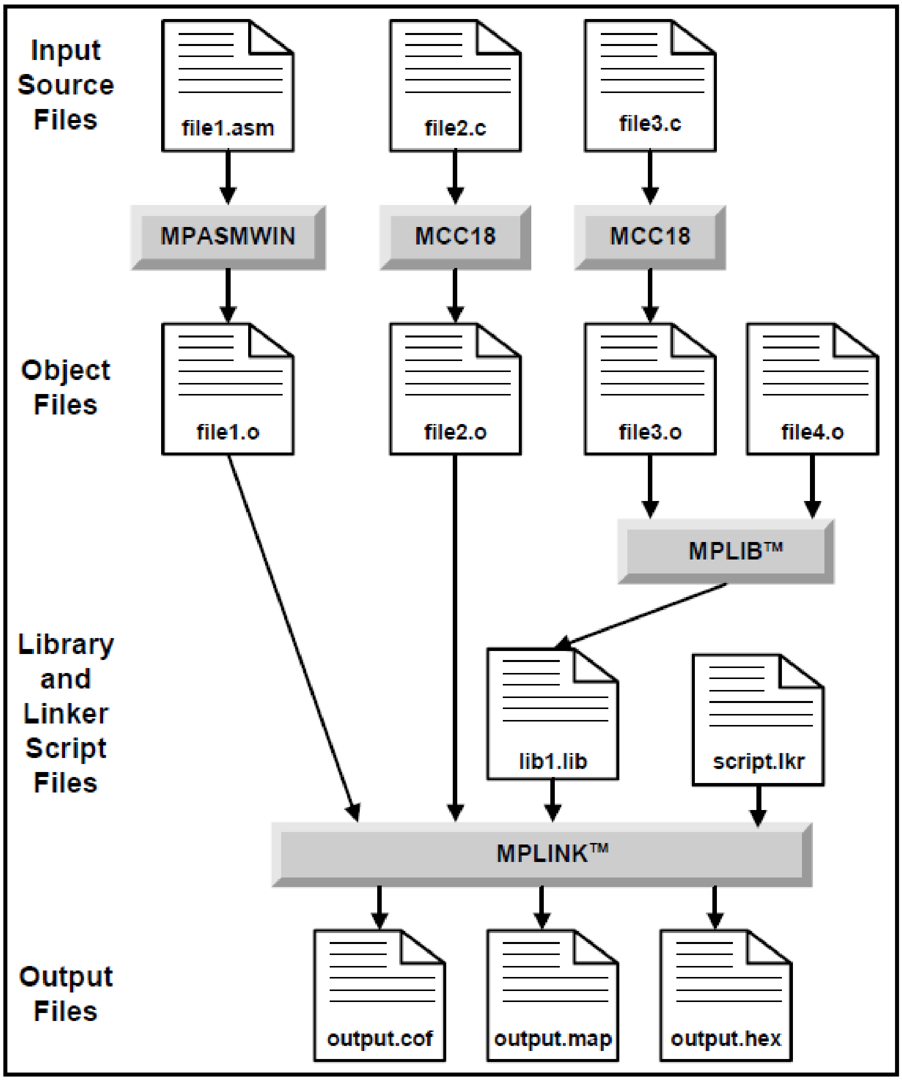


Figure 35: Execution Flow of Language Tools

6.3.3: Programmer:

The MPLAB ICD2 programmer is a low-cost usually used for evaluation, debugging and programming. Following features could be the valuable points for the programmer:

- ✓ Real-time and single-step code execution
- ✓ Breakpoints, register and variable watch or modify
- ✓ In-Circuit debugging
- ✓ Target V_{DD} monitor
- ✓ Diagnostic LEDs
- ✓ MPLAB IDE user interface
- ✓ RS-232 serial or USB interface to a host PC

Its help developers for debug source codes in their own application. It helps also to program a supported device by using microchip's ICSP protocol.

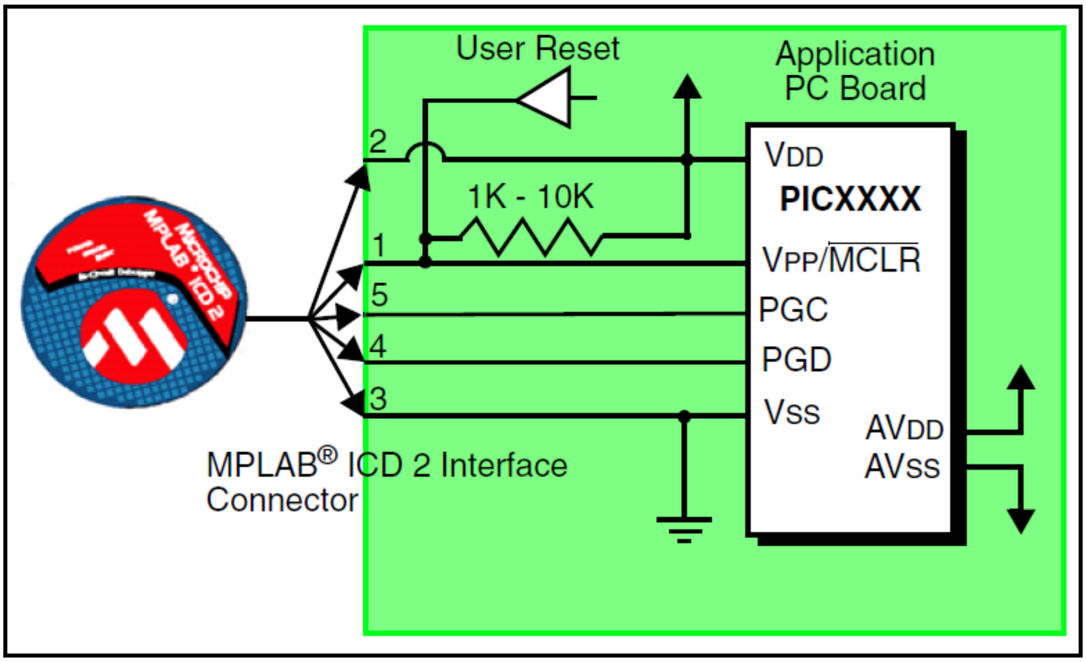


Figure 36: MPLAB ICD2 Connections

6.3.4: Operations Centre:

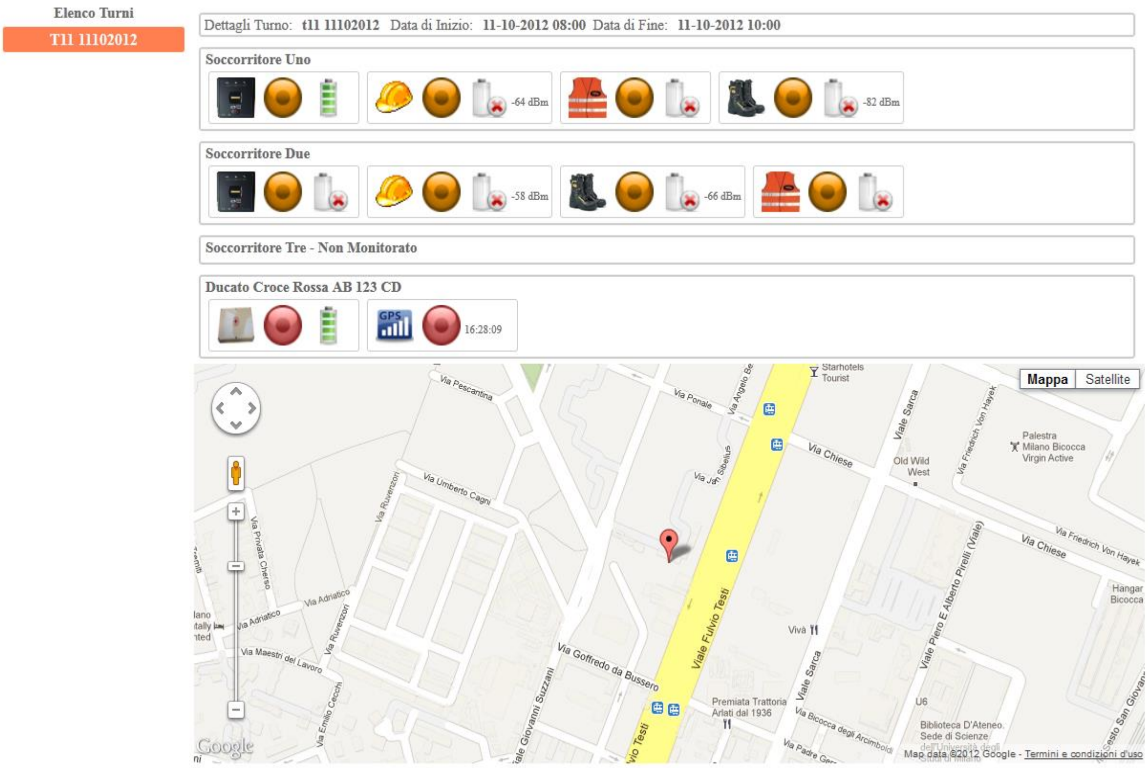
RESCUE SMART is designed to integrate easily with the computer systems and data management currently in use by extending the capabilities thanks to the accurate control of personnel and safety equipment on board the rescue vehicle.

The ability to monitor and steer the vehicle by the control center makes it more versatile and efficient way.

The management system consists of a Web Application simple and intuitive and allows you to:

- The management of the registry system that includes: men, vehicles, equipment and their setting.

- The programming of shifts: weekly programming.
- The real-time monitoring of the state of wear.
- The real-time verification of the presence of electro medical equipment
- The analysis of historical data.



6.3.5: Technical Service Centre:

The support service of technical assistance is delivered the Operation Management Center (OMC), which allows coverage of the following functional areas:

- SPOC Single Point Of Contact for the management of multi-channel requests for action (email, phone, fax, and web via the trouble ticketing system)
- Fault Management, for the management of the recovery actions and material faults
- Monitoring for real-time detection and warning alarms through the use of monitoring platforms by remote control at the stations and the OMC video wall

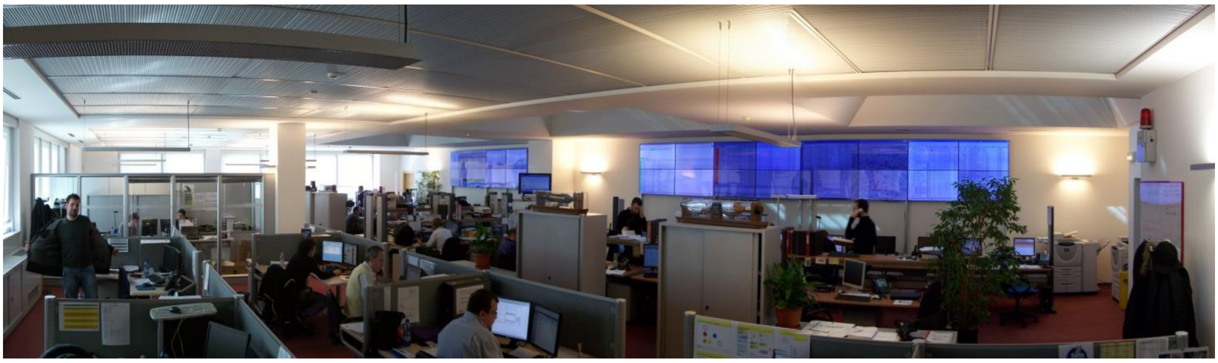


Figure 37: Operation Management Center

SMART RESCUE – The ally in emergency management:

Thanks to the continuous monitoring of operational staff involved in emergencies and certification that personnel are in the right place and with the necessary equipment and running, SMART RESCUE improve the effectiveness of rescue operations.

The numerous customizations also allow you to improve the operation of 'intervention or through a control for the safety of rescue personnel (hear, rate, temperature) which, thanks to an overview of the area where the rescue takes place.

Finally implementations such as the ability to transmit patient data in real time can be the determining factor in the response to a problematic situation.

Chapter 7: Experimental Study

7.1: Introduction

In these studies I have presented my real time experimental result based on delineated methodology. It has comprised in the implementation of several methods for synchronizing among components of the system such as master, sensor and moving object with Personal Protective Equipment (Helmets, Shoes and Jackets) which have been equipped with different firmware.

7.2: Experiment

Case I:

I have chosen 45 different points in floor and calculated their actual distance, then put the moving object in these points and achieved the received RSSI in the sensors. The distance of each point with respect to the master point as follows:

Points#	*Distances*	*Points#*	*Distances*	*Points#*	*Distances*	*Points#*	*Distances*	*Points#*	*Distances*
1	9.10 m	11	6.10 m	21	4.90 m	31	9.20 m	41	13.50 m
2	8.70 m	12	9.00 m	22	7.00 m	32	9.40 m	42	14.90 m
3	7.30 m	13	6.00 m	23	4.50 m	33	10.10 m	43	17.30 m
4	5.50 m	14	4.00 m	24	9.00 m	34	7.70 m	44	18.10 m
5	5.00 m	15	5.50 m	25	5.50 m	35	11.00 m	45	4.20 m
6	6.20 m	16	6.50 m	26	6.60 m	36	14.30 m		
7	4.70 m	17	9.90 m	27	8.20 m	37	11.60 m		
8	8.70 m	18	10.50 m	28	5.10 m	38	13.00 m		
9	10.10 m	19	7.50 m	29	9.60 m	39	16.50 m		
10	9.50 m	20	6.50 m	30	10.50 m	40	14.70 m		

Table 7: Distance between each point t to the master

All those point i have divided in two sets: Training-Set with 36 points and Testing-Set with 9 points to examine the model.

For each point i collected at least 10 values. The path loss exponent or β by Log-normal shadow function as below:

$$\overline{PL}(d) = \overline{PL}(d_0) + 10\beta\left(\frac{d}{d_0}\right) + X_\sigma$$

Here, according to my experiments $d_0 = 2\,m,$ & $\overline{PL}(d_0) = 130.$ In this application the system firstly eliminates X_σ and placing the average of RSSI and distance for each point for the above function and measure the β for each point. Finally the avg. of the values for β would be the path loss exponent of the system. Also by using the Least Square method as below:

$$r = f + 10\beta \log\left(\frac{d}{d_0}\right) + \varepsilon \quad where \quad f = 130,\ \ d_0 = 2 \quad \rightarrow \quad r = 130 + 10\beta \log d + \ \varepsilon$$

$$\rightarrow \quad \varepsilon = r - 130 - 10\beta \log d$$

$$from\ LS: \qquad J = \sum_{i=1}^{n=36} (\varepsilon_i)^2 = \sum_{i=1}^{n=36} (r_i - 130 - 10\beta \log d_i)^2$$

Calculate the partial derivative of J to β and let it equal to zero:

$$\frac{\partial J}{\partial \beta} = 20 \sum_{i=1}^{n=36} (10\beta \log d_i) + 130 - r_i) \log d_i = 0$$

And finally by below formula the β is calculated:

$$10\beta \sum_{i=1}^{n=36} (\log d_i)^2 + 130 \sum_{i=1}^{n=36} \log d_i - \sum_{i=1}^{n=36} r_i \log d_i = 0$$

From two ways the path loss exponent is computed around 4.39. Now we have to describe the Gaussian interference to the propagation of RSSI signals which in Log-normal shadow functionX_σ. Because of this reason set X as a standard Gaussian random number. Because X_σ is the zero mean Gaussian RV and σ is the population variance, so we get:

$$D(X_\sigma) = \sigma^2 \quad and \quad E(X_\sigma) = 0$$

And since,

$$D(\sigma X) = \sigma^2 \quad and \quad E(\sigma X) = 0$$

We obtained σX has the equal distribution asX_σ. Therefore it’s possible to replace X_σ with σX.

$$\overline{PL}(d) = \overline{PL}(d_0) + 10\beta \left(\frac{d}{d_0}\right) + \sigma X$$

By the most scientific literatures the variance function of RSSI or σ(d) usually derived by a polynomial degree 3 equation as:

$$\sigma(d) = Ad^3 + Bd^2 + Cd + e$$

Where A, B, C and e are undetermined coefficient, the values are dynamically adjusted according to different environment. To find them we can use Least Square by inserting y instead of σ(d) and summing the observational error to the equation as followings:

$$y = Ad^3 + Bd^2 + Cd + e + \varepsilon \quad \rightarrow \quad \varepsilon = y - Ad^3 - Bd^2 - Cd - e$$

$$J = \sum_{i=1}^{n=36} (\varepsilon_i)^2 = \sum_{i=1}^{n=36} (y - Ad^3 - Bd^2 - Cd - e)^2$$

According to the Least Square respectively we can calculate the partial derivative of J to a, b, c and e and for minimizing which is equal to 0:

$$\frac{\partial J}{\partial A} = 0, \quad \frac{\partial J}{\partial B} = 0, \quad \frac{\partial J}{\partial C} = 0, \quad \frac{\partial J}{\partial e} = 0$$

Finally by four below equations we can find the coefficients:

$$A \sum_{i=1}^{n=36} (d_i^6) + B \sum_{i=1}^{n=36} (d_i^5) + C \sum_{i=1}^{n=36} (d_i^4) + e \sum_{i=1}^{n=36} (d_i^3) - \sum_{i=1}^{n=36} (y_i d_i^3) = 0$$

$$A \sum_{i=1}^{n=36} (d_i^5) + B \sum_{i=1}^{n=36} (d_i^4) + C \sum_{i=1}^{n=36} (d_i^3) + e \sum_{i=1}^{n=36} (d_i^2) - \sum_{i=1}^{n=36} (y_i d_i^2) = 0$$

$$A \sum_{i=1}^{n=36} (d_i^4) + B \sum_{i=1}^{n=36} (d_i^3) + C \sum_{i=1}^{n=36} (d_i^2) + e \sum_{i=1}^{n=36} (d_i) - \sum_{i=1}^{n=36} (y_i d_i) = 0$$

$$A \sum_{i=1}^{n=36} (d_i^3) + B \sum_{i=1}^{n=36} (d_i^2) + C \sum_{i=1}^{n=36} (d_i) + ne - \sum_{i=1}^{n=36} (y_i) = 0$$

$d_{i:}$ is the distance of the point to the master point, y_i : is the subtraction of received RSSI, expected RSSI in calibration phase both are known. For computing y_i, after getting path loss exponent or β, systems put the distance value in to the Log-normal path loss model without considering the random Gaussian variable, calculates the expected RSSI so :

y_i = *received* RSSI – *expected* RSSI

By placing the distance into above function instead of x, y_i in each step is measured.

According to data the values of these coefficients are founded:

A = 0.0038 B= -0.1510 C= 2.6520 d = -12.7940

By putting the received RSSI in to the Log-normal shadow model, the Log-normal distance is measured and putting this value into the variance function of RSSI or σ(d) with multiplying its result by random Gaussian number the result can be a positive (+) or negative(-) value.

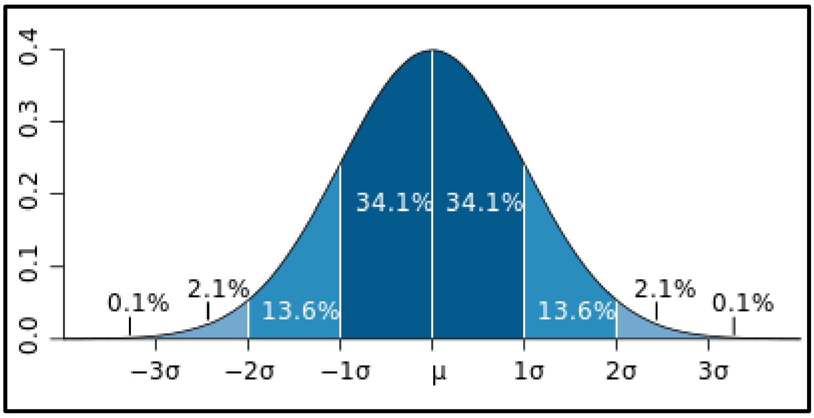


Figure 38: Standard Deviation

According to standard deviation figure if the result of $\sigma(d) \times X$ is positive it means that the RSSI value is more than that value which we expected so we subtract it from RSSI. For negative result this value should add to the RSSI. Finally with new RSSI and Log-normal shadow model I found the estimated distances.

The value Training-Set and Test-Set have been calculated on Matlab and Excel as well:

	Distances	Received RSSI Value	Expected RSSI Value	y
	9.10	74	101	27
	8.70	106	103	-3
	7.30	102	107	5
	5.50	118	110	-8
	5.00	118	115	-3
	6.20	132	114	-18
	4.70	108	109	1
	8.70	108	100	-8
	10.10	94	98	4
	9.50	92	102	10
	6.10	88	105	17
	9.00	102	103	1
	6.00	120	111	-9
	4.00	129	120	-9
	5.50	123	114	-9
	6.50	119	111	-8
	9.90	97	98	1
	10.50	84	99	15
	7.50	80	107	27
	6.50	120	109	-11
	4.90	125	115	-10
	7.00	126	108	-18
	4.50	127	131	4
	9.00	98	103	5
	5.50	106	109	3
	6.60	109	104	-5
	8.20	113	105	-8
	5.10	121	108	-13
	9.60	100	102	2
	10.50	103	97	-6
	9.20	99	99	0
	9.40	102	102	0
	10.10	109	99	-10
	7.70	91	106	15
	11.00	96	96	0
	14.30	88	92	4
	11.60	98	95	-3
	13.00	95	94	-1
	16.50	72	92	20
Sum:	320.00	4092.00	4092.00	0.00
STDEV:	-	15.33	7.96	

Table 8: Training-Set

Therefore the model depicted as:

$$\overline{PL}(d) = 130 + 10 \times 4.39 \times \log d + \left((0.0038)d^3 + (-0.1510)d^2 + (2.6520)d - 12.7940\right)X$$

Now we can run the model for the Test-Set:

#	Distance	Received RSSI	LogNormal Distance	σ(d)	Gaussian Rnd N	σ(d)*GaRndN	Expected RSSI	Estimated Distance	Dis Error	RSSI Error
1	2.20	132	1.43	-9.57	-8.03E-01	7.69	124.31	2.26	-0.06	7.69
2	3.90	125	2.17	-7.97	9.50E-01	-7.58	132.58	1.38	2.52	-7.58
3	4.80	135	1.20	-10.11	-2.06E+00	20.78	114.22	4.11	0.69	20.78
4	5.90	132	1.43	-9.57	8.94E-01	-8.55	140.55	0.86	5.04	-8.55
5	11.50	95	12.88	4.80	-3.02E-01	-1.45	96.45	11.82	-0.32	-1.45
6	13.90	98	10.78	3.17	-1.02E+00	-3.24	101.24	8.89	5.01	-3.24
7	15.70	100	9.57	2.16	2.40E+00	5.19	94.81	13.03	2.67	5.19
8	16.30	101	9.02	1.67	-1.68E+00	-2.80	103.80	7.64	8.66	-2.80
9	17.50	120	10.78	3.17	-1.69E+00	-5.36	125.35	13.07	4.47	-5.35

Table 9: Test-Set & Results

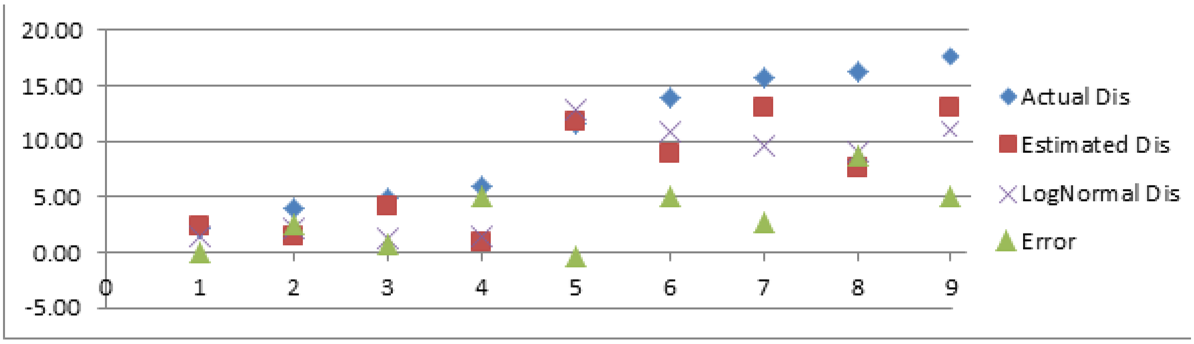


Figure 39: Comparison among Actual Dis, Estimated Dis and Log-Normal Dis

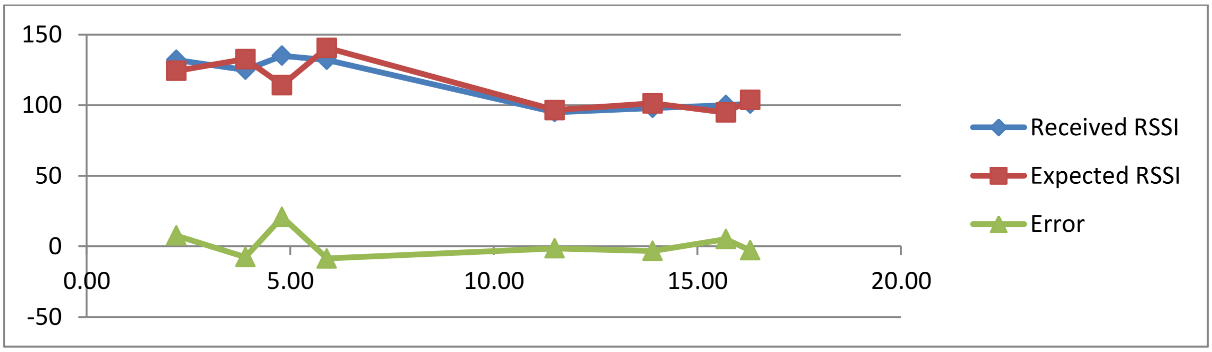


Figure 40: Plot of Received & Expected RSSI

I have simulated the model again with new Test-Set; I have obtained the following results as below:

#	Distance	Received RSSI	LogNormal Distance	σ(d)	Gaussian Rnd N	σ(d)*GaRndN	Expected RSSI	Estimated Distance	Dis Error	RSSI Error
1	1.5	123	2.44	-7.41	2.28E+00	-16.94	139.94	0.89	0.61	-16.94
2	2.3	132	1.43	-9.57	4.91E-02	-0.47	132.47	1.39	0.91	-0.47
3	2.4	118	3.28	-5.80	-1.11E+00	6.44	111.56	4.81	-2.41	6.44
4	2.8	133	1.35	-9.76	-1.65E+00	16.13	116.87	3.51	-0.71	16.13
5	3.4	130	1.61	-9.17	1.28E-01	-1.17	131.17	1.50	1.90	-1.17
6	3.5	122	2.59	-7.12	-2.86E-01	2.03	119.97	2.92	0.58	2.03
7	3.6	133	1.35	-9.76	2.39E-01	-2.33	135.33	1.17	2.43	-2.33
8	4.1	103	8.01	0.69	-2.28E+00	-1.57	104.57	7.29	-3.19	-1.57
9	4.4	133	1.35	-9.76	-2.33E-01	2.27	130.73	1.54	2.86	2.27
10	4.8	133	1.35	-9.76	2.69E-01	-2.63	135.63	1.15	3.65	-2.63
11	6.00	122	2.59	-7.12	3.49E-01	-2.48	124.48	2.23	3.77	-2.48
12	6.9	125	2.17	-7.97	7.78E-01	-6.21	131.21	1.50	5.40	-6.21
13	7.00	118	3.28	-5.80	-1.80E+00	10.47	107.53	6.12	0.88	10.47
14	10.00	115	3.92	-4.69	-2.28E+00	10.70	104.30	7.41	2.59	10.70
15	11.30	123	2.44	-7.41	-3.63E-01	2.69	120.31	2.86	8.44	2.69
16	12.60	110	5.28	-2.59	5.18E-01	-1.34	111.34	4.88	7.72	-1.34
17	16.80	100	9.57	2.16	-6.37E-01	-1.38	101.38	8.82	7.98	-1.38

Table 10: Second Test-Set and its Results

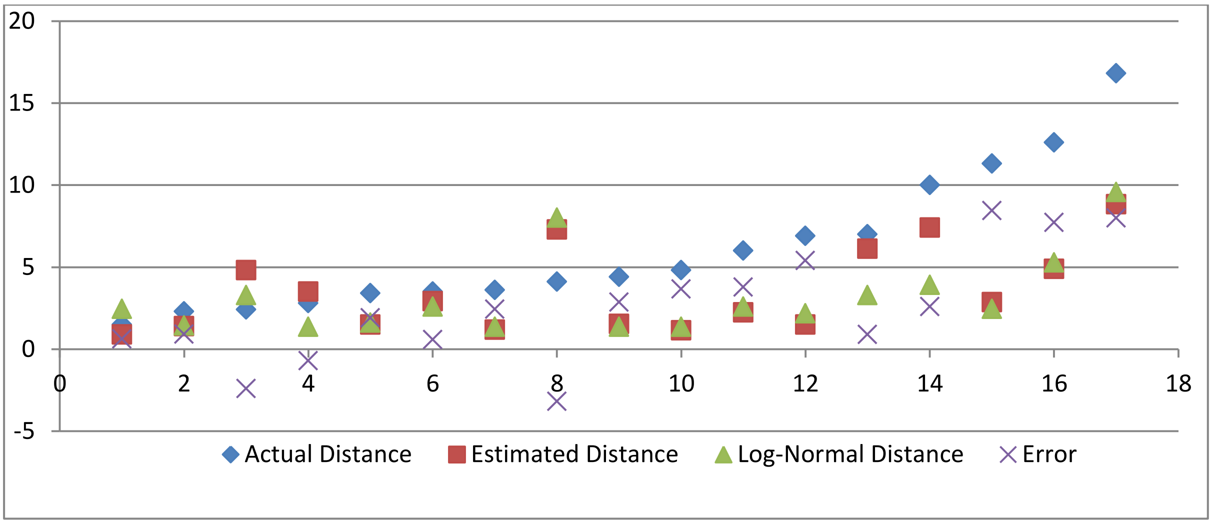


Figure 41: Plot Comparison among Actual Dis, Estimated Dis and Log-Normal Dis.

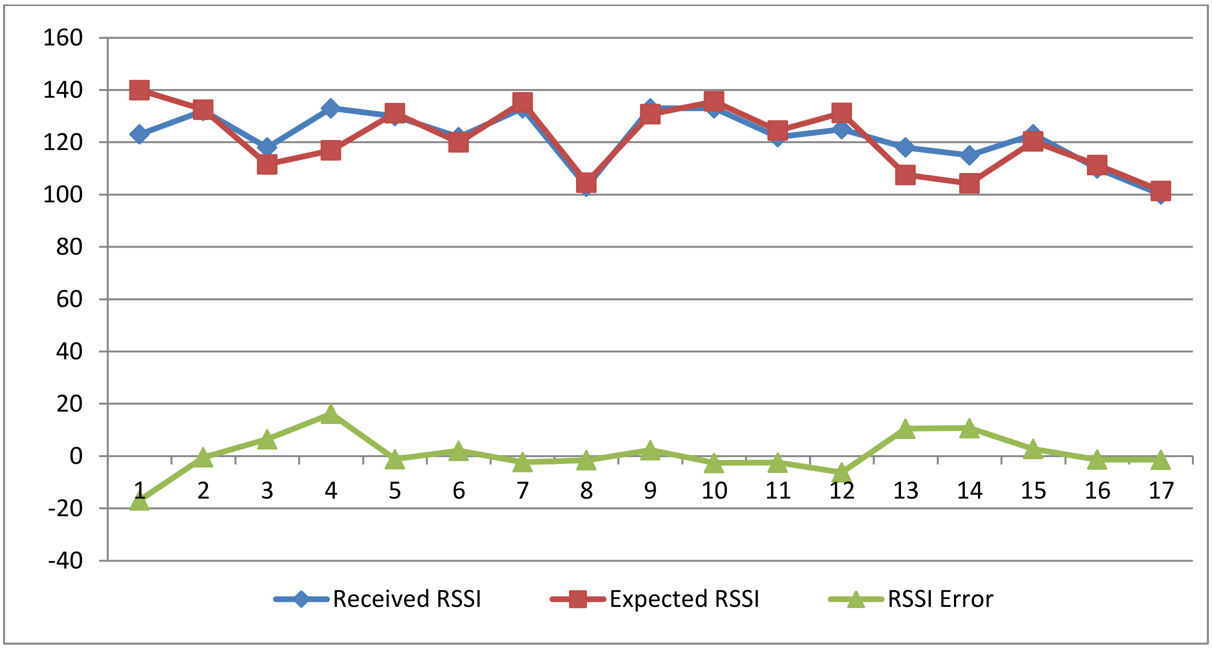


Figure 42: Plot between Received and Expected RSSI

Case II:

To run the system I have chosen an open air wide area at Italian Red Cross in Milano where almost there was no barrier. Sensors were able to communicate in line of sight condition to each other. This experiment for measuring the RSSI values between the moving object and sensors. By considering different value for each distance the path loss exponent measured by the proposed system.

The obtained results as below:

Location: Italian Red Cross, Milan, Italy				
Weather: Sunny			Wind Speed: 10 Km/h	
Humidity: 51%			Sound Average: 48 dB	
Precipitation: 20%			Average RSSI(2m): 130	
Number	Distance in meter	RSSI	β Coefficient	LOS/NLOS
1	1.50	125	3.41	LOS
2	2.30	112	5.25	LOS
3	3.00	102	6.29	LOS
4	3.60	97	6.30	LOS
5	4.30	91	6.79	LOS
6	5.10	85	6.50	LOS
7	5.90	81	6.62	LOS
8	6.70	82	5.93	LOS
9	7.50	77	6.40	LOS
10	8.30	67	7.07	LOS
11	9.00	65	7.23	LOS
12	9.90	56	7.83	LOS
13	10.70	63	6.70	LOS
14	11.90	56	7.99	LOS
15	13.00	63	6.10	LOS
16	14.20	57	6.59	LOS
17	15.50	63	5.71	LOS
18	16.30	61	5.86	LOS
19	17.50	47	6.68	LOS
20	18.40	48	6.48	LOS
21	19.80	38	7.17	LOS
22	20.90	53	5.90	LOS
23	22.00	59	5.43	LOS
24	23.20	52	5.78	LOS
25	24.40	57	5.48	LOS
26	25.50	60	5.12	LOS
27	26.80	43	6.23	LOS
28	27.90	48	5.74	LOS
29	28.80	38	6.44	LOS

Table 11: Outcome for Experiment

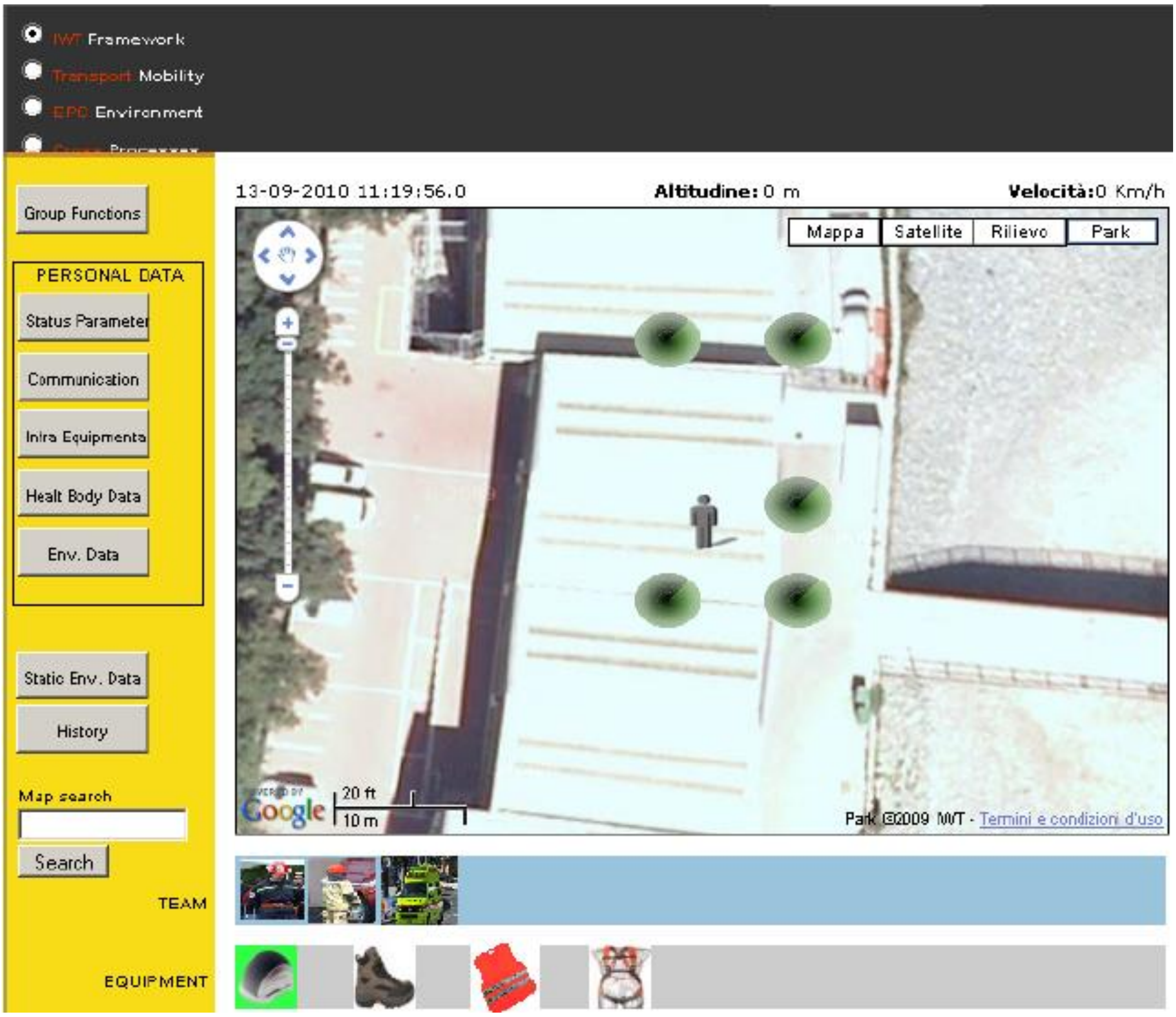


Figure 43: Snapshot of a page

The average β for this this test is 6.24. Following plot showed the comparison between RSSI-Distance and β-RSSI. While the distance between the moving object and sensor increased the RSSI value decreased on the other hand the received RSSI value in such kind of environmental condition is smaller than in the interior environment.

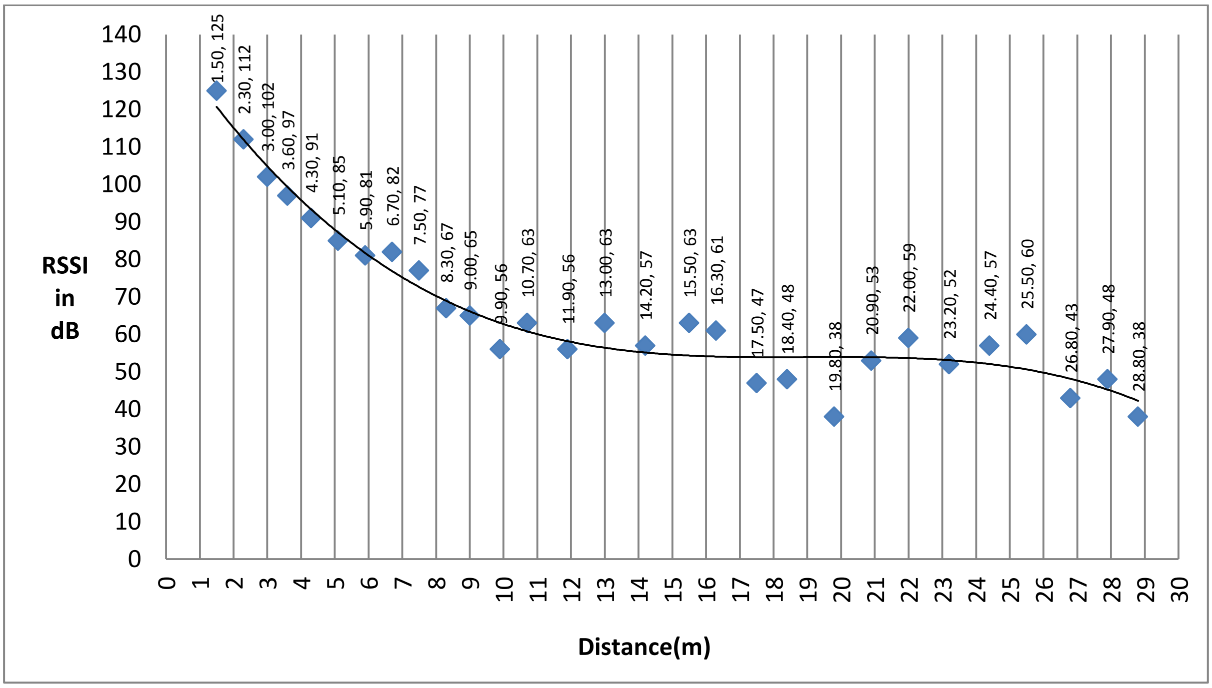


Figure 44: Plot Distance vs. RSSI

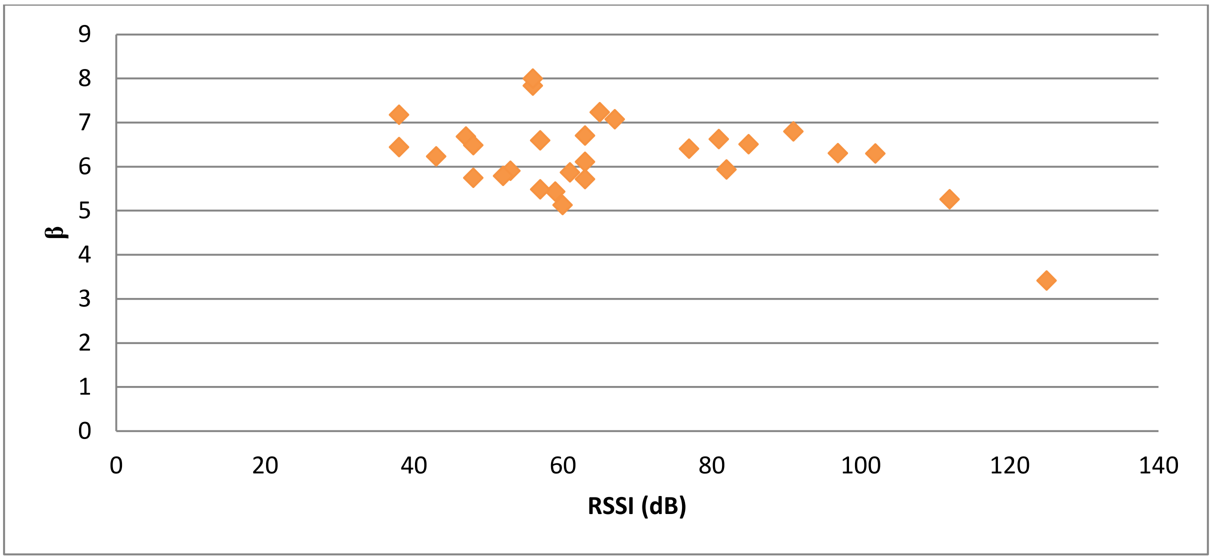


Figure 45: Plot between RSSI-β

For measuring the path loss exponent and coefficients with random Gaussian function of training set this system has best tested. They system gives the following result:

Distances	Received RSSI Signal	Expected RSSI Signal	Estimated Distance	Distance Error	RSSI Error
3.60	97	105.21	3.35	0.25	-8.21
6.70	82	73.16	10.94	-4.24	8.84
9.00	65	65.43	14.55	-5.55	-0.43
13.00	63	65.04	14.76	-1.76	-2.04
14.20	57	62.59	16.16	-1.96	-5.59
16.30	61	55.86	20.72	-4.42	5.14
20.90	53	53.72	22.42	-1.52	-0.72
24.40	57	58.62	18.71	5.69	-1.62
26.80	43	49.97	25.74	1.06	-6.97
27.90	48	49.67	26.03	1.87	-1.67

Table 12: Test Results

Here is given the plot on the Actual, Log-normal, Estimated distance with error. As below:

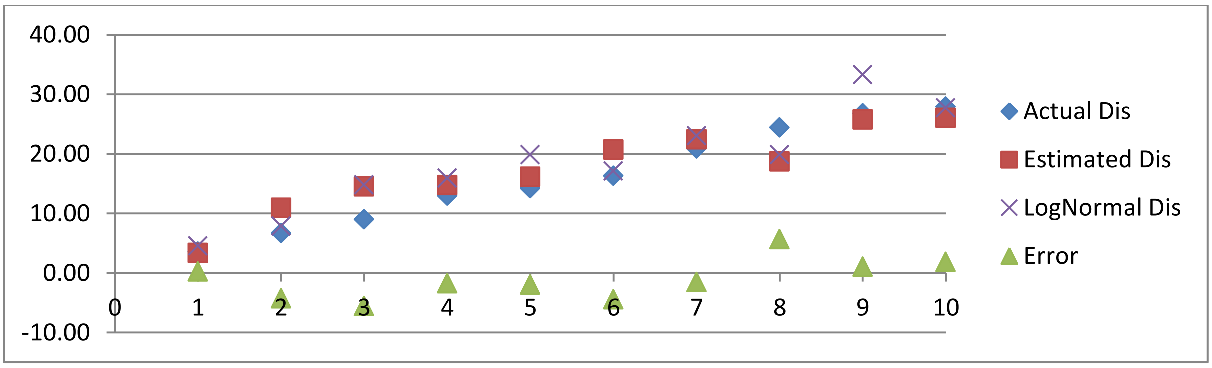


Figure 46: Plot among Actual Dis, Estimated Dis and Log-Normal Distance

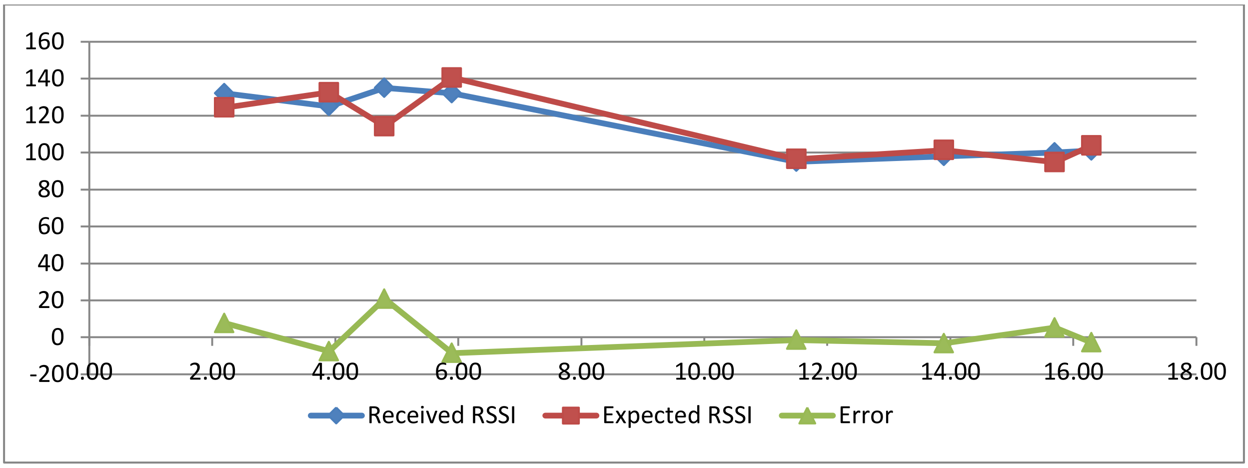


Figure 47: Plot for Received and Expected RSSI

Following has given one more experimental result in the area Istituto Piero Pirelli, Via Fulvio Testi in Milan, as below:

Location: Istituto Piero Pirelli, Via Fulvio Testi, Milan, Italy				
Weather: Cloudy			Wind Speed: 8 Km/h	
Humidity: 68%			Sound Average: 59 dB	
Precipitation: 25%			Average RSSI(2m): 130	
Number	Distance in meter	RSSI	β Coefficient	LOS/NLOS
1	6	100	5.15	LOS
2	19	81	5.00	LOS
3	14	76	5.61	LOS
4	22	64	5.44	LOS
5	35	55	5.35	LOS
6	39	75	3.68	LOS
7	46	68	4.05	LOS
8	53	77	3.77	LOS
9	56	57	4.71	LOS
10	60	47	4.95	LOS
11	65	62	4.25	LOS
12	71	66	3.85	LOS
13	75	57	4.32	LOS
14	82	50	4.36	LOS
15	87	52	4.92	LOS
16	95	55	4.40	LOS
17	105	60	4.05	LOS
18	120	70	4.46	LOS

Table 13: Outcome for the second experiment

Figure 48: Field Test in Istituto Piero Pirelli, Via Fulvio Testi, Milan, Italy

The following figure showed the relationship between RSSI-Distance and RSSI-β is as follows:

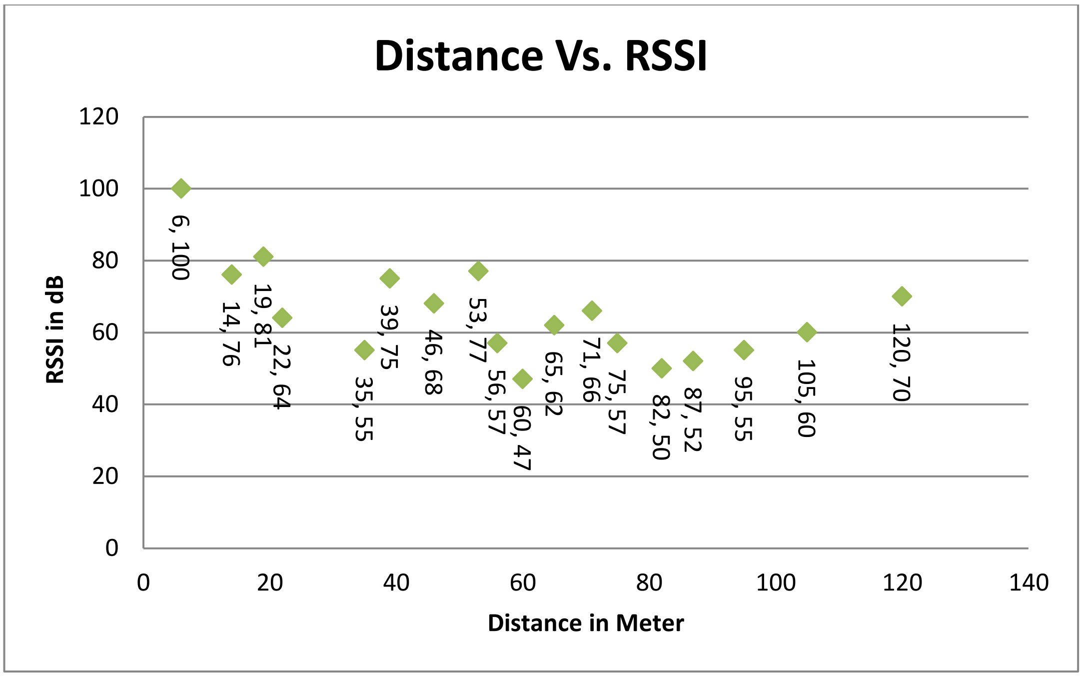


Figure 49: Plot between Distances - RSSI Diagram

Distance	Received RSSI	Expected RSSI	Estimated Dis	Dis Error
2.5	132	140.55	1.55	0.95
4.9	120	134.35	1.75	3.15
6.8	100	110.46	5.15	1.65
11.6	90	98.46	7.75	3.85
19	86	95	20.12	-1.12
25	70	77.55	25.32	-0.32
33	60	70.69	33.65	-0.65
38	50	66.45	38.75	-0.75
45	45	60.49	50.85	-5.85
59	40	58.15	65.53	-6.53

Table 14: Test Results

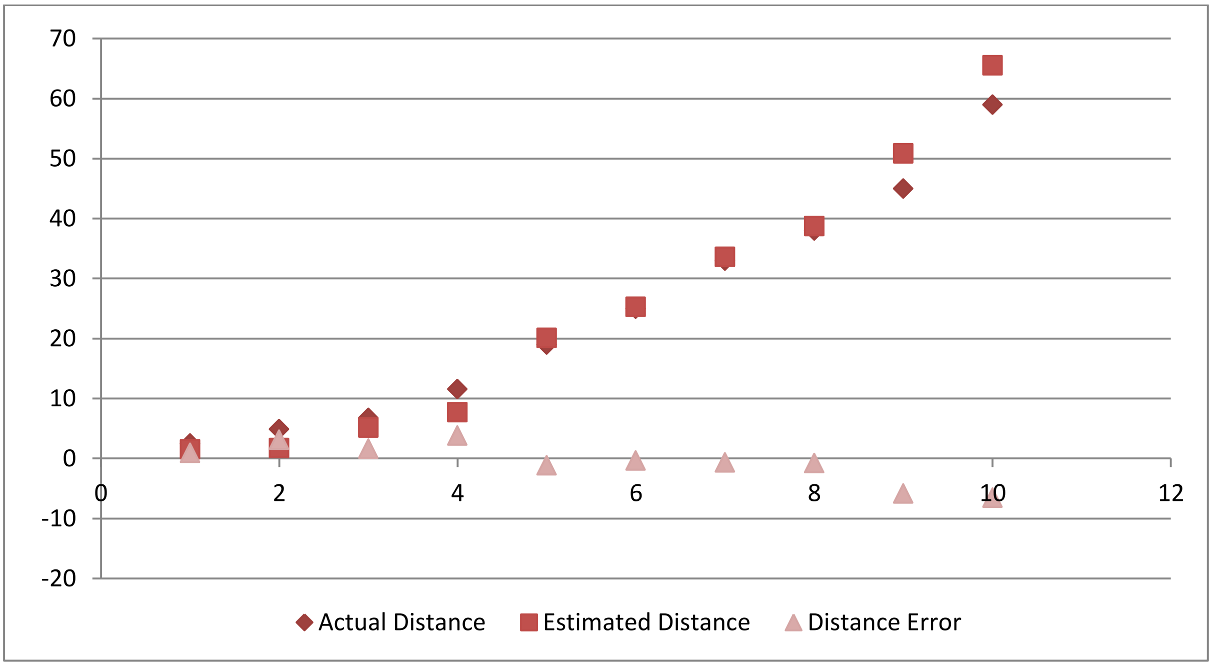


Figure 50: Comparison plot among Actual Dis, Estimated Dis and Log-Normal Dis

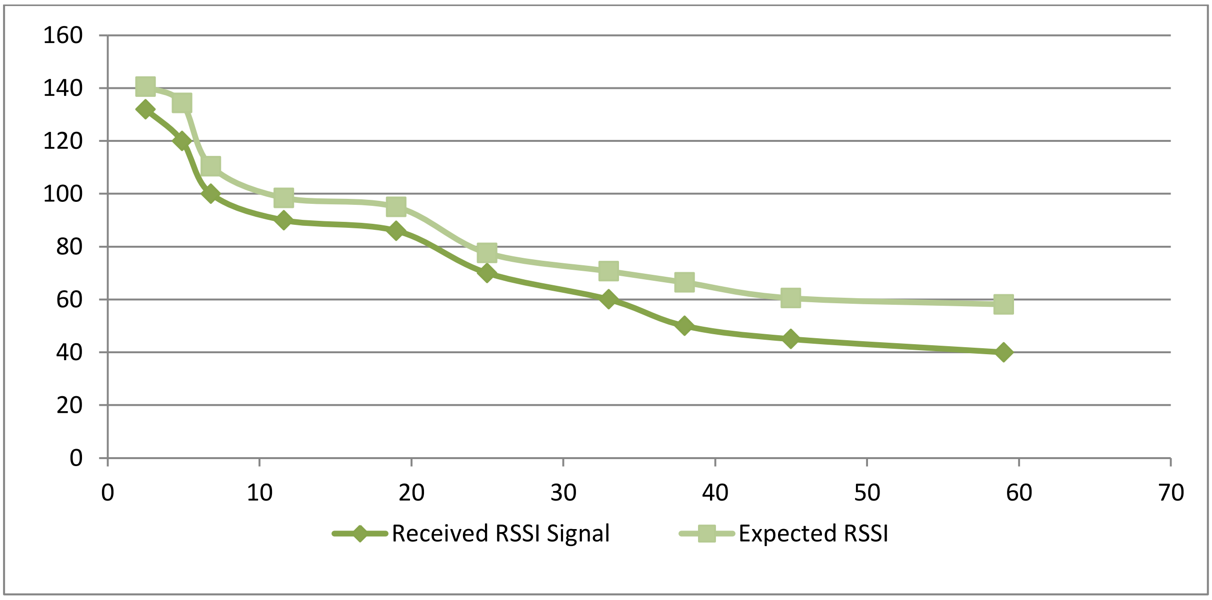


Figure 51: Plot Received and Expected RSSI

Case III:

The Crews localization problem for determine the exact position for a route step event with motion and map of the environment.

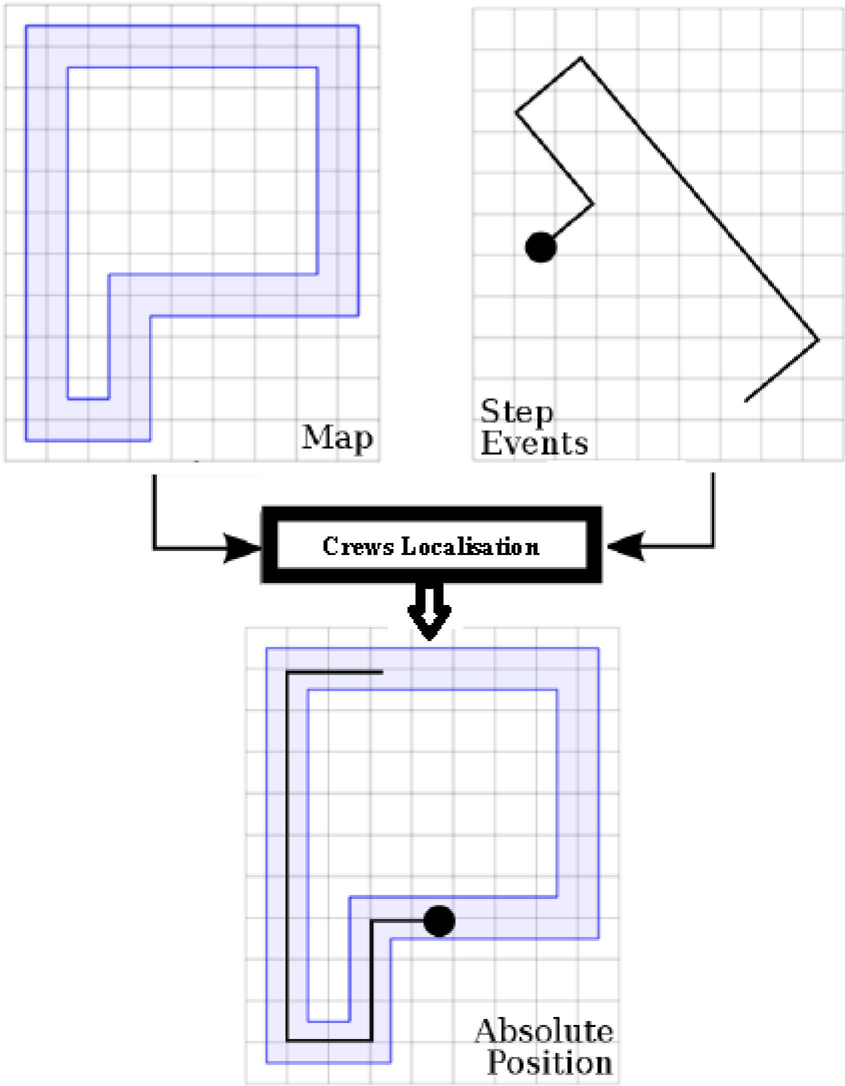


Figure 52: Crews Route Map

An experimental application of my methodology in Italian Red Cross, Milan, a three storied building which floor area with 94955 square feet. In figure-49 we can see the path (route) followed by the crew's with the steps achieved by the inertial sensor are as below:

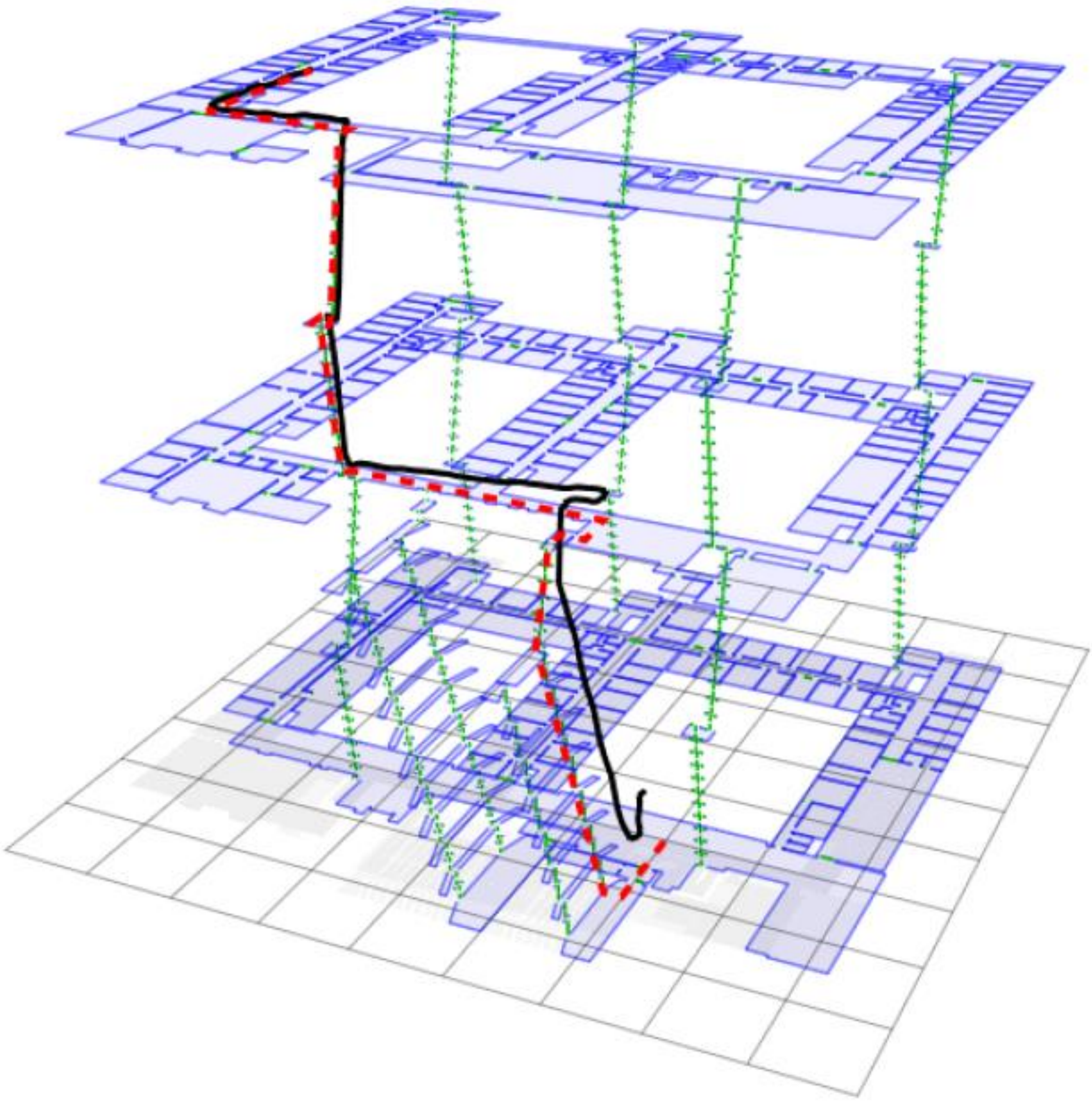


Figure 53: The path followed by the Crew's

The sensor values to correct drift for the Gyroscope's over time. Following is the plot I have achieved from actual data to demonstrate the drift from the gyroscope:

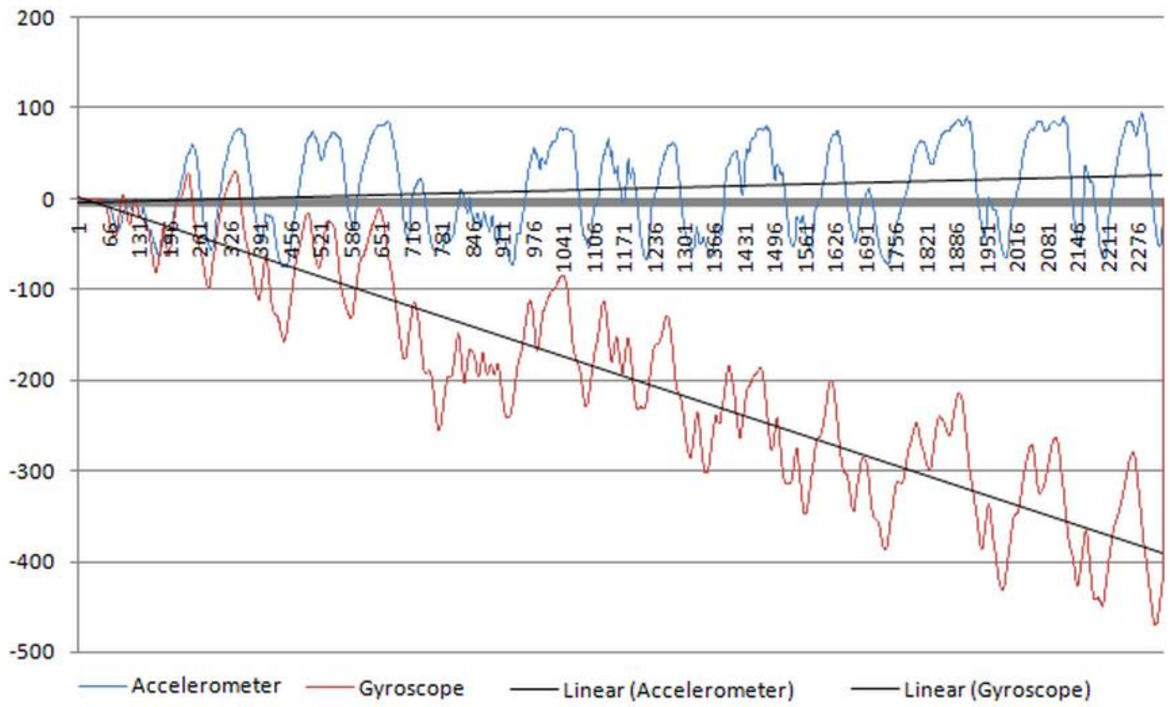


Figure 54: Plot of data the gyroscope.

After filtering the data the following graph illutstrating my results:

Results-1:

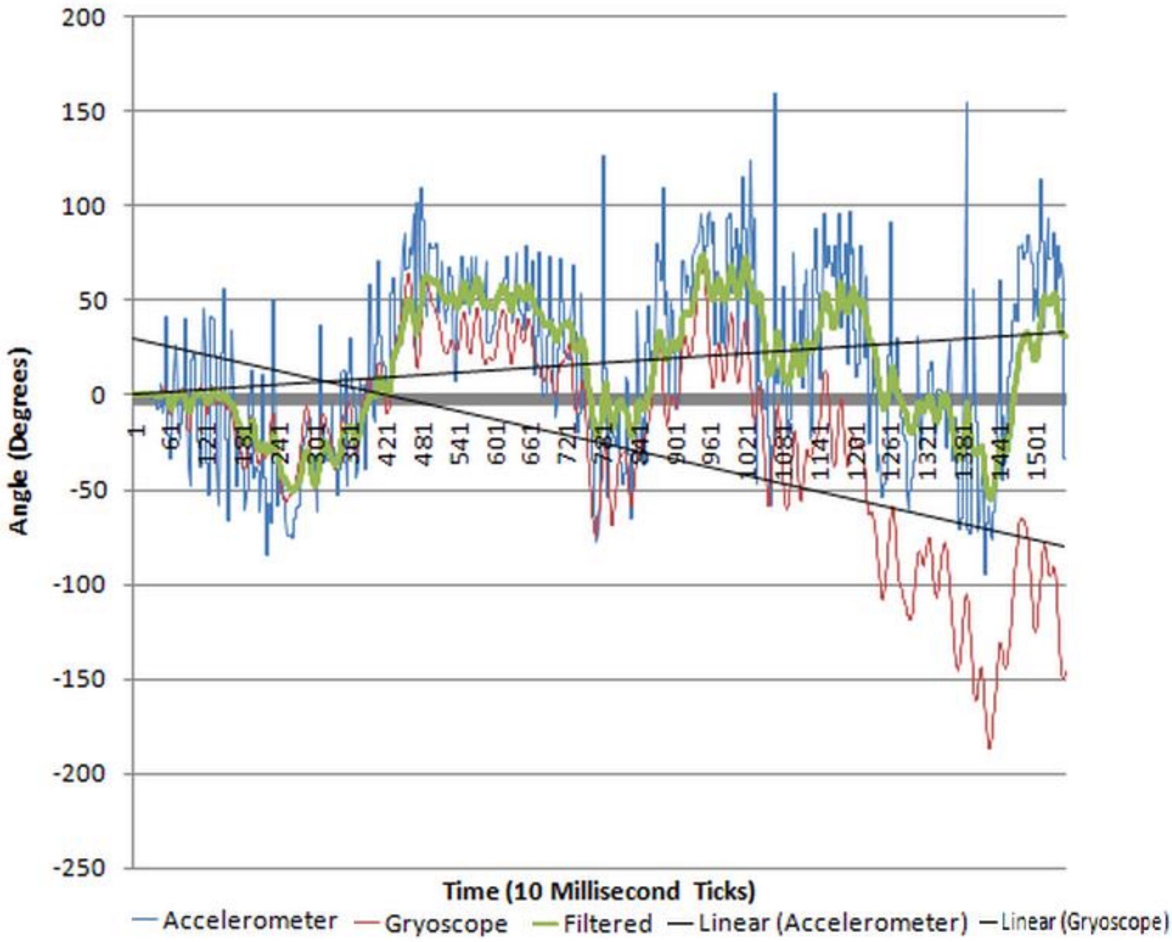


Figure 55: Filtered data outcome1

Here I can see the filter corrects for gyroscopic drift and fuses both signals into a single smooth signal

Results-2:

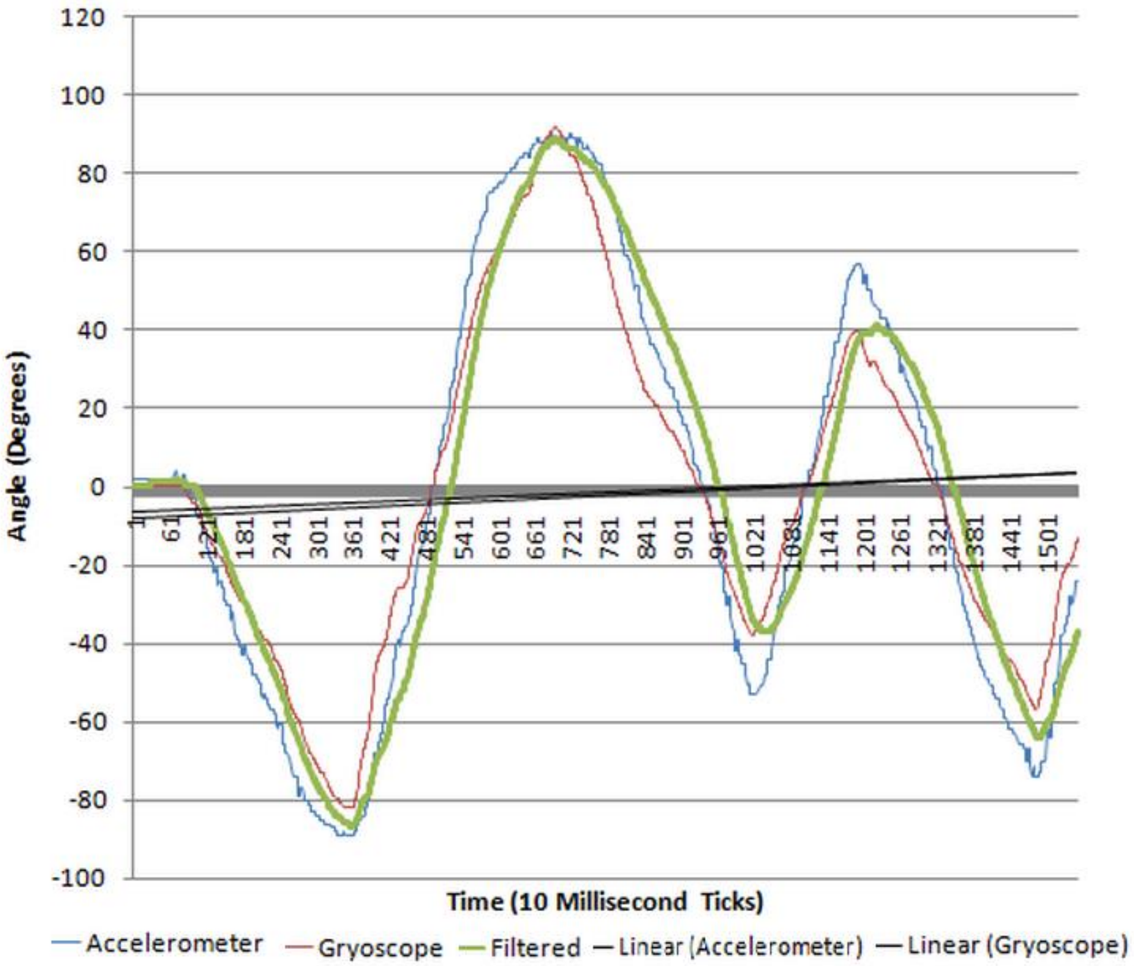


Figure 56: Filtered data outcome2

Chapter 8: System Application

8.1: Why such kind of System!!

Almost every day workers are losing their valuable life during working period. It's may needed quick help and support for them in any kind of incident or in dangerous situation. By using such kind of system we can reduced the number of victims in any risky situation. To do that we can monitor the workers position and status and momentarily can be possible to help them in any emergency condition. To do so firstly we need to find their perfect position or location. After getting position we could collect the workers' health status and working environment. For worker safety and security it would potential to have controlled positions and status for humans at that moment.

8.2: Accuracy:

In area of telecommunication for wireless sensor networks related works there are various methods, algorithms and protocols. Also infrastructures which has brought out by different Researchers, Research Institution and Engineers tried to ameliorate the accuracy and the performance of the systems. Utilization of them is very crucial since the system have to be authentic so that in any dangerous situation can trust on it without any error. But it's very essential to optimize the system repeated for stable accuracy. In my system have better accuracy comparing to others system.

8.3: Decisive Points:

There are some critical points as:

- ✓ The Position of Unknown Beacons (Workers or Crews)

The location of crews or mobile object find by the RSSI information which comes from anchor node.

- ✓ Supervise the current status of the crews or workers

By receiving the Personal Protective Equipment (helmets, boots and jackets) Packets from the sensors the status of the crews at the moment is typical.

- ✓ Tracing the path of the crews or mobile object

By saving the position information of the crews or workers in every time, it can show path in two or three dimensional models. Moreover organizing and controlling the Personal Protective Equipment (helmets, boots and jackets) Packets by particular middleware estimate the performance and accuracy of the system.

8.4: Usefulness or application of such kinds of systems?

Earlier I have introduced different circumstances where localization system can be very useful for improving overall systems performance. The possibility of any risky situation is also reduced by these systems.

Here I have introduced three useful areas as follow:

8.4.1: Garments and Industrial:

By knowing the positions of the workers or labors particularly who needs more aid at the moment is really critical. For controlling their critical situation used current status of workers this system will be very effective for improving their safety and performances.

8.4.2: Security for the Firefighters:

In emergency situations like fire in residential or industrial area and grand supermarkets so on it fitted out by localization and tracing system could be securer. For example fire in a huge building while smoke reduced the eyesight of the firefighters. Such kind of situation using localizing and tracing their locations the master can lead them very sufficiently.

8.4.3: Surveillance for Airport:

In wireless sensor network surveillance for airport is considered as one of the most significant practical applications. By scheduling of algorithm for detecting target usurpation used the unique characteristic of network.

8.5: Areas of currently use:

Already operating with 118 rescues in central Italy, SMART RESCUE is very flexible by extending the possibilities for operation to the different needs through a series functions can be implemented on request.

In the specific customizations have been identified that increase the usability of the system such as:

- Monitoring of equipment and vital signs of rescue personnel that combined with geo-location, dramatically increase the safety of personnel. Consequently, in particularly complex situations such as in the case of urban or forest fires will be able to intervene if escape routes or new fronts modify the intervention area.

- Monitoring and transmission of patient data is delivered to the control center that the relief facilities to which the medium is addressed. These supports provide additional support to the staff for first aid and inform the doctors at the hospital on how to arrange the rescue.
- Control of the area managed by the drones via emergency rescue personnel in order to identify the scope of action and move the rescue personnel to avoid areas of obvious danger.
- Triangulation signal for emergencies in inaccessible areas
- Create wireless networks for communication / data / image transmission between operators and operations center.

Conclusion and Future Developments

Conclusion

In this dissertation I have described, implemented and proposed system to find the location of mobile object based RSSI signal with inertial navigation system. These models establish a simulator which utilized to develop and test localization algorithms. It has comprised in the implementation of several methods for synchronizing among components of the system such as master, sensor and moving object with Personal Protective Equipment (Helmets, Shoes and Jackets). The device was placed at foot of the crews since it is most effective position for accurate crews' location estimation.

The experimental result showed localization algorithm provides efficient solution for estimating workers or crew's trajectories. The system measured path loss exponent value (β) and Gaussian random variable (X_σ) with zero-mean. It facilitated to have specific model for suggesting the empirical data. By comparing the actual and estimated distance we can have such kind of model, according to this comparison it possible to determine shape of error and also for minimizing error we can select specific model such as polynomial model. Depending on the environmental situation model can vary zero mean Gaussian random variable can solve this problem. Such a system could be used where the installation of high accuracy absolute location system is either too expensive or impractical.

Future Developments

Future developments can be focused on to gaining a periodic absolute positioning modification during a walk or movement to eliminate any drift. My experimental result shows localization error less than 1m 95% of the time is very promising so we may improve it in the future by significantly using the Extended Kalman Filter (EKF) which can be implemented to get less noise estimation. Through the implementation of Extended Kalman Filter 100% accuracy can be achieved.

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Appendix:

Data Set Obtained From Inertial Measurement Unit:

Here this the data series enclosed as sample of the data set which have been used during real time experiment. This data set continues up to 7355 entries, all of whom can't be displayed here.

gyro_x	gyro_y	gyro_z	acc_x	acc_y	acc_z	alfa x	alfa y	alfa z	acc x m/s2	acc y m/s2	acc z m/s2	g	hz	P
-50	78	-13	-448	64	17088	-0,00803094	0	0	-0,26810547	0,03830078	10,2263086	16384	95	0,01052632
-49	79	-19	-512	-128	17152	-0,01590126	0,01268889	-0,00305176	-0,00640625	-0,07660156	10,2646094			
-60	70	-1	-512	-128	17152	-0,02553839	0,02393221	-0,00321238	-0,00640625	-0,07660156	10,2646094			
-53	85	-1	-320	-256	17152	-0,03405119	0,03758481	-0,003373	0,10849609	-0,15320313	10,2646094			
-50	84	-5	-512	128	17152	-0,04208213	0,05107679	-0,00417609	-0,00640625	0,07660156	10,2646094			
-46	71	1	-640	192	17152	-0,0494706	0,06248073	-0,00401547	-0,08300781	0,11490234	10,2646094			
-33	78	4	-512	-64	17088	-0,05477102	0,07500899	-0,003373	-0,00640625	-0,03830078	10,2263086			
-36	79	8	0	-576	17024	-0,0605533	0,08769788	-0,00208804	0,3	-0,34470703	10,1880078			
-46	78	18	64	0	16704	-0,06794177	0,10022615	0,00080309	0,33830078	0	9,99650391			
-33	73	47	-1088	576	17216	-0,07324219	0,11195133	0,00835218	-0,35111328	0,34470703	10,3029102			
-44	55	117	-704	640	17152	-0,08030942	0,12078536	0,02714458	-0,12130859	0,38300781	10,2646094			
-70	69	250	-768	192	17216	-0,09155273	0,13186806	0,06729929	-0,15960938	0,11490234	10,3029102			
-84	78	345	-704	64	17216	-0,10504472	0,14439633	0,12271279	-0,42130859	0,03830078	10,3029102			
-82	65	299	-576	-64	17152	-0,11821546	0,15483655	0,17073782	-0,34470703	-0,03830078	10,2646094			
-62	43	150	-576	-64	17152	-0,12817383	0,16174316	0,19483064	-0,34470703	-0,03830078	10,2646094			
-50	53	45	-576	-128	17152	-0,13620477	0,17025596	0,20205849	-0,34470703	-0,07660156	10,2646094			
-58	66	21	-576	-64	17152	-0,14552066	0,18085681	0,20543149	-0,34470703	-0,03830078	10,2646094			
-70	87	-5	-512	-128	17088	-0,15676398	0,19483064	0,20462839	-0,30640625	-0,07660156	10,2263086			
-73	108	-24	-512	-64	17088	-0,16848916	0,21217748	0,20077354	-0,30640625	-0,03830078	10,2263086			
-89	107	-25	-512	0	17024	-0,18278423	0,22936369	0,19675807	-0,30640625	0	10,1880078			
-78	108	-8	-448	0	17152	-0,1953125	0,24671053	0,19547312	-0,26810547	0	10,2646094			
-87	98	2	-448	0	17152	-0,20928634	0,26245117	0,19579436	-0,26810547	0	10,2646094			
-61	84	20	-448	-64	17152	-0,21908409	0,27594315	0,19900673	-0,26810547	-0,03830078	10,2646094			
-58	93	36	-512	-64	17088	-0,22839998	0,29088071	0,20478901	-0,30640625	-0,03830078	10,2263086			
-71	89	52	-512	-64	17024	-0,23980392	0,30517578	0,21314119	-0,30640625	-0,03830078	10,1880078			
-66	68	62	-448	-64	17088	-0,25040476	0,31609786	0,22309956	0,01189453	-0,03830078	10,2263086			
-73	62	58	-448	-64	17088	-0,26212993	0,32605623	0,23241545	0,01189453	-0,03830078	10,2263086			
-83	76	42	-512	0	17088	-0,2754613	0,33826326	0,23916144	-0,02640625	0	10,2263086			
-84	101	14	-448	0	17152	-0,28895328	0,35448576	0,2414101	0,01189453	0	10,2646094			

Image of Data Set2:

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	T	U
1	wx	wy	wz	ax	ay	az	f.f.		w pitc	w roll	W yaw	pitch	roll	yaw	ax m/s	ay m/s	az m/s	vy	vz
2	-305	-303	-208	128	0	16128	0		-4.65	-4.623413086	-3.173828125	-0.04898874	-0.04866751	-0.03340872	0.07664063	0	9.65671875		0
3	-232	-292	-185	64	-64	16064	0		-3.54	-4.455566406	-2.822875977	-0.08625231	-0.09556821	-0.0631232	0.03832031	-0.038320313	9.618398438		-0.001953626
4	-184	-277	-158	64	0	15936	0		-2.81	-4.22668457	-2.410888672	-0.11580618	-0.14005962	-0.08850098	0.03832031	0	9.541757813	9.804992879	-0.004713809
5	-144	-255	-151	64	-64	15872	0		-2.2	-3.890991211	-2.304077148	-0.13893529	-0.18101742	-0.11275442	0.03832031	-0.038320313	9.5034375	9.804975251	-0.007877106
6	-67	-219	-130	0	-64	15936	0		-1.02	-3.341674805	-1.983642578	-0.14969675	-0.21619295	-0.13363487	0	-0.038320313	9.541757813	9.804950677	-0.010636732
7	28	-198	-95	-128	-64	15808	0		0.43	-3.021240234	-1.449584961	-0.14519942	-0.24799548	-0.14889366	-0.07664063	-0.038320313	9.465117188	9.804922239	-0.014202832
8	69	-173	-84	-320	0	15872	0		1.05	-2.639770508	-1.281738281	-0.13411672	-0.27578253	-0.16238564	-0.19160156	0	9.5034375	9.804896735	-0.01736535
9	98	-131	-71	-576	0	15872	0		1.5	-1.998901367	-1.083374023	-0.11837608	-0.2968236	-0.17378958	-0.34488281	0	9.5034375	9.80487667	-0.020527687
10	91	-90	-70	-704	0	15872	0		1.39	-1.373291016	-1.068115234	-0.10375977	-0.3112793	-0.18503289	-0.42152344	0	9.5034375	9.804859558	-0.023689898
11	71	-55	-62	-896	0	15936	0		1.08	-0.839233398	-0.946044922	-0.09235583	-0.32011333	-0.19499126	-0.53648438	0	9.541757813	9.803847516	-0.02644865
12	63	-17	-39	-832	64	16064	0		0.96	-0.259399414	-0.595092773	-0.08223684	-0.32284385	-0.2012554	-0.49816406	0.038320313	9.618398438	9.804839221	-0.028400606
13	106	13	-20	-768	192	16192	0		1.62	0.198364258	-0.305175781	-0.06521125	-0.32075581	-0.20446777	-0.45984375	0.114960938	9.695039063	9.804834231	-0.029545819
14	174	37	4	-576	192	16192	0		2.66	0.564575195	0.061035156	-0.03726357	-0.31481291	-0.2038253	-0.34488281	0.114960938	9.695039063	9.804834248	-0.030691092
15	214	59	37	-384	256	16192	0		3.27	0.900268555	0.564575195	-0.00289114	-0.3053364	-0.1978824	-0.22992188	0.15328125	9.695039063	9.804840004	-0.031836469
16	246	76	79	-320	192	16128	0		3.75	1.159667969	1.205444336	0.03662109	-0.29312937	-0.18519351	-0.19160156	0.114960938	9.65671875	9.804849921	-0.033385333
17	270	115	92	-256	192	16128	0		4.12	1.754760742	1.403808594	0.07998818	-0.2746582	-0.17041658	-0.15328125	0.114960938	9.65671875	9.804860759	-0.03493429
18	299	144	101	-64	128	16000	0		4.56	2.197265625	1.541137695	0.12801321	-0.25152909	-0.15419408	-0.03832031	0.076640625	9.580078125	9.804869679	-0.037290076
19	304	170	140	0	64	16064	0		4.64	2.593994141	2.136230469	0.17684133	-0.22422389	-0.13170744	0	0.038320313	9.618398438	9.804877789	-0.039242525
20	304	197	124	-64	64	16128	0		4.64	3.005981445	1.892089844	0.22566946	-0.19258198	-0.11179071	-0.03832031	0.038320313	9.65671875	9.804881046	-0.040791572
21	309	178	95	0	64	16192	0		4.71	2.716064453	1.449584961	0.27530068	-0.16399183	-0.09653192	0	0.038320313	9.695039063	9.804878216	-0.041937146
22	283	140	68	0	0	16128	0		4.32	2.136230469	1.037597656	0.32075581	-0.14150519	-0.08560984	0	0	9.65671875	9.804868561	-0.043485861
23	241	69	22	0	0	16192	0		3.68	1.052856445	0.335693359	0.35946495	-0.13042249	-0.08207622	0	0	9.695039063	9.804846654	-0.044630886
24	180	18	-48	0	0	16192	0		2.75	0.274658203	-0.732421875	0.38837634	-0.12753135	-0.08978593	0	0	9.695039063		-0.045775545
25	132	-25	-116	-64	0	16128	0		2.01	-0.381469727	-1.770019531	0.40957802	-0.13154682	-0.10841771	-0.03832031	0	9.65671875		-0.047323247
26	24	-69	-183	-192	0	16192	0		0.37	-1.052856445	-2.792358398	0.41343287	-0.14262952	-0.13781096	-0.11496094	0	9.695039063		-0.048467296
27	-69	-108	-254	-256	64	16128	0		-1.05	-1.647949219	-3.875732422	0.40235017	-0.15997636	-0.17860814	-0.15328125	0.038320313	9.65671875		-0.050014618
28	-156	-146	-294	-256	64	16064	0		-2.38	-2.227783203	-4.486083984	0.37729364	-0.18342671	-0.22583008	-0.15328125	0.038320313	9.618398438		-0.051965372
29	-233	-176	-345	-320	0	16256	0		-3.56	-2.685546875	-5.264282227	0.33986945	-0.21169562	-0.28124358	-0.19160156	0	9.733359375		-0.052706191
30	-289	-186	-390	-320	64	16192	0		-4.41	-2.838134766	-5.950927734	0.29345061	-0.24157072	-0.34388492	-0.19160156	0.038320313	9.695039063		-0.053850629