NEAR GROUND TARGET SIGNAL LOCALIZATION AT 433 MHz USING IMPROVED TRILATERATION METHOD

by

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DECLARATION

I declare that this thesis is the result of my own research, that it does not incorporate without acknowledgement any material submitted for the degree or diploma in any university and does not contain any materials previously published, written or produced by another person except where due references are made in the next.

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LIST OF ABBREVIATIONS

AH	Antenna Height
DGPS	Differential GPS
ECA	Error Correction Algorithm
Fr	Fresnel Radius
FSL	Free Space Loss
GPS	Global Positioning System
LOS	Line of Sight
NI-DAQ	National Instrument Data Acquisition
non-LOS	non Line of Sight
RF	Radio Frequency
RFID	Radio Frequency Identification
RSS	Received Signal Strength
TOA	Time of Arrival

LIST OF SYMBOLS

r_{a1}, r_{a2}, r_{a3}	Radius of 1st, 2nd and 3rd circles of Trilateration
r_{m1}, r_{m2}, r_{m3}	Measured radius from target to center of 1st, 2nd and 3rd circles of Trilateration
Δx , Δy	Offset error for localized target coordinate
x_t , y_t	Target coordinates
x'_t , y'_t	Target coordinate after correction
r_{a1}, r_{a2}, r_{a3}	Actual radiuses
δ_1, δ_2 , δ_3	Actual offset error during distance measurements of r_{a1}, r_{a2}, r_{a3}
δ_E	Maximum possibility of expected error
P_R	Receiving power strength
P_T	Transmitting power strength
G_R	Receiving antenna gain
G_T	Transmitting antenna gain
Λ	Wavelength
Loss	power loss in dB
D	Path length
A_a	Amplitude attenuation
γ	Complex propagation constant
α	Attenuation constant
β	Phase constant
μ	Permeability
ε	Permittivity
L_f	Losses due to the foliage in dB, in ITU Vegetation model
d_m	Distance vs. loss (the new RSS model) in meter
L_m	loss vs. distance, temperature and antenna height (the new RSS model) in (dB)
Φ	Variable related on temperature and environmental factors
Θ	Variable related to antenna height
H	Antenna height in meter
T	Temperature in Celsius (^{0}C)
Ss	Signal strength vs. output voltage

*

LOKALISASI ISYARAT SASARAN BERHAMPIRAN BUMI PADA 433 MHz MENGGUNAKAN KAEDAH TRILATERASI YANG DIPERTINGKATKAN

ABSTRAK

Melokalisasikan sasaran berhampiran bumi dengan kaedah Trilaterasi membayangkan kedudukan kordinat sasaran menuju satu titik asas yang diketahui dengan jarak sukatan dari sasaran tidak kurang dari tiga titik rujukan yang dikenalpasti. Sukatan jarak di antara tiga sisi Trilaterasi boleh dijalankan dengan teknik-teknik sukatan berbeza seperti RSS atau TOA.

Dalam kajian ini, teknik sukatan RSS telah digunakan untuk mengkaji konsep Trilaterasi untuk menentukan lokasi ke atas antena aras rendah (lebih kurang 1 m ke 3 m tingginya dari tanah) pada bacaan 433 MHz. Pada mulanya, model sukatan jarak berlawanan dengan kehilangan berkaitan dengan tinggi antenna telah disukat. Model itu berdasarkan kepada eksperimen-eksperimen yang dilaksanakan dalam persekitaran yang berbeza, iaitu ruang lapang yang terbuka, dan kawasan penanaman (penanaman kelapa sawit) dengan semak samun beraras rendah. Model julat RSS yang diperolehi digunakan untuk proses lokalisasi Trilaterasi dalam menenetukan lokasi sasaran (dalam koordinat) dengan menyukat jarak dari sasaran kepada nod-nod rujukan yang dikenalpasti. Keseimbangan berikutan dari ralat penyerakan dan lain-lain fenomena yang diketahui telah diperbetulkan menggunakan satu algoritma inovatif yang dikenali sebagai Algoritma Pembetulan Ralat atau *Error Correction Algorithm* (ECA).

Hasilnya, konsep Trilaterasi menggunakan RSS telah berjaya dikembangkan dan diaplikasikan dalam kajian ini. Pelbagai model penyerakan telah diperolehi dan dapatan menunjukkan beberapa perkaitan dengan model-model lain untuk kehilangan laluan. Dari analisis tersebut, kehilangan penyerakan yang paling tinggi

dilaporkan berada pada bacaan sehingga 5.25 dB/m dalam kawasan penanaman (pokok palma) dengan kanopi seperti payung dan sedikit semak samun. Tambahan lagi, dengan pengenalan ECA dan GUI yang dikembangkan secara khusus, penambahbaikan yang mampu menentukan lokasi sebenar telah meningkat sehingga 44%. Ini menunjukkan bahawa keseimbangan lokasi sasaran yang disukat disebabkan oleh ralat penyerakan telah beralih lebih rapat kepada kordinat sasaran yang sebenarnya.

NEAR GROUND TARGET SIGNAL LOCALIZATION AT 433 MHz USING IMPROVED TRILATERATION METHOD

ABSTRACT

Localizing near ground target with Trilateration method implies the positioning of target coordinate towards a known base point with measuring distance from target to no less than three recognized reference points. Distance measurement between three sides of Trilateration could be performed with different measurement techniques such as RSS or TOA.

RSS measurement technique was used by this research to investigate the Trilateration concept for determining location on low level antenna (approximately 1 to 3 m height above ground) at 433 MHz. Initially distance measurement model versus losses relating to antenna height was measured. The model was based on experiments conducted in different environments, namely, flat open space and vegetation area (palm tree plantation) with very low level shrubs. RSS range model obtained was used for Trilateration localization process in determining target location (in coordinates) by measuring distances from target to recognized reference nodes. Offset due to propagation error and other known phenomenon were corrected using an innovative algorithm known as Error Correction Algorithm (ECA).

As a result, Trilateration concept using RSS was successfully developed and applied in this study. Various propagation models were obtained and the results showed some correlation with other known models for path loss. From the analysis, worst case propagation losses were recorded up to 5.25 dB/m in the vegetation area (palm tree) with umbrella

like canopy and low shrubs. In addition, with the introduction of ECA and specially developed GUI, improvements determining the actual location have improved up to 44%. This implies that measured target location offset due to propagation error has shifted closer to the actual target coordinate.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Tracking, tracing or chasing of an item, has been employed since many years ago with different techniques and technologies. There are different purposes for tracking such as animal for hunting as the food supply, or insect tracking by the biologists and agricultural points, husbandry or personal-pet keeping, wildlife conservation or studying biology of the insect or animal.

Different methods and equipments such as RFID or RF measurement, harmonic radar identification, GPS and Satellite, have been applied for animal tagging which are shortly reviewed through this study in chapter two. All tracking methods are associated with remote distance measuring which might use a remote distance measurement such as RSS (Received Signal Strength), TOA (Time of Arrival) or RADAR measurement, etc.

In RSS measurement method, signal strength is measured by receiver and compared with the transmitted signal strength. Then, distance between the transmitter and receiver is calculated based on the signal strength reduction along the path. The signal strength reduction is associated with factors such as distance between two stations, antenna height from ground, environment temperature, link clarity, obstacle existence and many other factors. The most obvious cause of extra power reduction through the path is the absorption loss by the obstacles. Therefore, unexpected errors for RSS range measurement will appear. The concept of different type of power loss such as absorption, reflection, scattering and also different type of noises are reviewed in this research.

Positioning a target through 2-dimensional plan can be carried out by Trilateration or Triangulation. Trilateration is a technique that calculates the coordinate of a target relative to one recognized base point. It needs to measure distance from target to at least three recognized points.

1.2 Problem Statement

Presently, different tracking instruments and techniques are available for object tracking. Since these are designed for near ground tracking environment, climate may affects their applications, because of foliages or trees that cause higher losses. Even now, there are not enough correlated studies for the case of this research area, especially in tropical climate.

The Trilateration localization method which is implemented in this work requires a distance measurement between the target-point and at least three recognized reference points. As distance measurement among the three sides of Trilateration, were done by RSS technique due to its cost effectiveness, accessibility and moderate accuracy, then proper model was required to calculate distance versus losses with respect to low antenna height and high temperature tropical plantation.

Since loss through the path depends on many factors such as permeability and permittivity of the medium or any other existing obstacle, then it is very difficult or even impossible to calculate losses theoretically. But it can be completed similar to the conventional method of predicting losses via the practical path loss models. Since the model has any inaccuracy then offset error will appear for distance calculation based on the path loss and causes offset error for target positioning with Trilateration method. Consequently, to improve Trilateration positioning accuracy, an error correction algorithm was also required.

1.3 Aims and Research Scope

This study meant to prove the concept of target localization with Trilateration method to apply for the near ground targets at 433 MHz. This research aimed to improve and recover the offset errors of target localized position. Localization was expected to utilize a data logging system to accelerate the positioning time.

RSS range measurement method is used through the research and applied with UHF frequency band (433 MHz). UHF was chosen because of simple design of equipment in this range of frequency and accessibility of practical circuits and equipment at the lab. Available circuits and transponders were used during path loss modeling.

1.4 Research Objectives

The objectives of this research are to:

1. Prove the concept of positioning target with Trilateration method
2. Implement the concept of near ground target localization with Trilateration method
3. Improve the accuracy of localized position in Trilateration by introducing Error Correction Algorithm (ECA).

1.5 Contributions of this Study

Contributions from the research are:

1. Modeling of power loss through a planar field, for short antenna height and respect to the Fresnel radius was done.
2. Power Loss through other environments such as grassy field and Palm Oil Plantation was studied for distance up to 20m.
3. Proof of Trilateration concepts using the new RSS model dedicated for near ground antenna.
4. Modeling of Trilateration localization with real-time data logging through LABVIEW software and using NI-DAQ for data logging.
5. NI-DAQ was properly applied for data logging from and RF-Power detector to a PC and analyzed the acquired data with the LABVIEW software in order to localize the target point with Trilateration method.
6. A new Error-Correction-Algorithm (ECA) was operated to improve the Trilateration accuracy with a MATLAB m-file program.

1.6 Overview of Thesis

Chapter 2 covers the literature review on animal and insect tracking, localization methods, remote distance measurement techniques and path loss prediction which are associated with this research. The experiments for measuring and modeling losses through distances and experiments of Trilateration's concept is proven in *chapter 3*. A new *Error Correction Algorithm (ECA)* suggested by this research is explained in chapter 3.

Chapter 4 includes results of experiments mentioned in chapter 3. Firstly, results of power loss measurement through different types of ground were implemented with two of different antenna height. After that, results of power loss on the open area covered by asphalt, with short antenna height, compared with FSL model and new power loss model prepared for similar climate as the experimental environment (tropical with high humidity) and near ground antenna (one to three meters). The model is compared with results of two other environments (on the grass, inside the palm oil plantation) and additional loss due to the Palm Oil Trees are discussed and compared with some existing propagation model of dense foliage losses. Chapter 4, also includes results of Trilateration localization on the flat and rigid open area which utilized the RSS range measurement technique and applies the proposed propagation model by this research. Output results taken from LABVIEW and NI-DAQ device are also presented for Trilateration localization using a linear RF-Power detector. Then results of new Error-Correction-Algorithm (ECA), which is applied on Trilateration positioning outcome, are presented and compared.

A conclusion of thesis is presented in Chapter 5 has proved the Trilateration concept, and RSS range measurement with the proposed new ECA. It also describes the Fresnel consideration for improving the path loss model. Results from new ECA, applying have also been discussed which affectively improved the Trilateration target position. At the end of chapter 5, a cost-effective circuit is proposed as to be continued in future work of this research which can be used for TOA range measurement technique to compare with the RSS outputs.

CHAPTER 2

LITERATURE REVIEW

2. 1 Overview

The main idea for this study is insects' and small animals' tracking, therefore different methods and studies about tracking them are reviewed and presented in this chapter. RSS and TOA distance measurement techniques are also reviewed and compared together. Finally, different existing models for power loss prediction, associated with RSS range measurement, have also been reviewed.

2. 2 Review on Animal and Insect Tracking Methods

Animal tracking has been employed since many years ago with different techniques and technologies. Historically, animals were trailed for hunting as the food supply but, it is now studied for many purposes such as wildlife conservation, pest control or personal pet keeping. It is an interesting subject for different disciples such as chemistry, biology, ecology, climatology and geography (Why study Insect, 1997). It is used by biologist and useful for husbandry. It is also important for similar tracking applications such as football soccer's tracking through the field or the crime tracking and so on.

The first tracking of birds refers to 1803 when an American biologist wanted to study about the bird's migration and make sure whether the bird returns to the same place in the next migration period. It was done by binding a string to the bird's leg, before the bird was migrates. This method was not trustworthy, as the bird could be lost or die. Therefore, a remote tracking method was needed for tracking animals or any living creatures that might be lost.

Radio tracking systems were created around 1939, and RADAR systems developed for military tracking plans during the Second World War. However, these techniques were not helpful for biologists or other nonmilitary tracking applications. In the early 1980's, with the Radio Frequency microchips arrival, insects tracking was tested (Boiteau et al. 2010). Satellite tracking for large fishes such as the sharks was made by Kerstetter (Kerstetter, Polovina & Graves 2004), and later on GPS animal-necklace was designed for dog tracking. RFID tags and RF chips have also been broadly applied for tracking items and animals.

Currently, GPS (Global Positioning System) which is handled by satellites is widely applied for positioning and tracking applications. Recently, harmonic radar tag has been used by Boiteau (Boiteau et al. 2010) to track the Colorado-Potato-Beetle (CPB) over an extended area.

An important limiting factor in animal or insect tracking is the size of animal which defines the attached tag to the animal or insect. Their habitat and their behavior such as flight speed and flight height, which indicate how fast or far-reporting the device used should be, is another limiting factor in animal or insect tracking. In the following, the advantages and disadvantages of animal tracking using RF, satellite and GPS technologies are discussed.

2.2.1 Radio Frequency Tracking Technology

Radio Frequency (RF) is a rate of oscillation in the range of 3 kHz to 300GHz which is dedicated into different bands such as LF (Low Frequency), HF (High Frequency) or UHF (Ultra High frequency). Radio Frequencies are also allocated by ITU-R for international spectrum management such as Air-Band, Marine-Band, ISM-Band, Land Mobile-Band and others.

RF tracking involves a transmitter called tag, attached to target and a receiver in the other side which is called RF reader. Coverage of RF tracking depends on many factors such as the signal frequency or the antenna efficiency.

Radio Frequency Identification (RFID) is a technology of applying radio waves for automatic identifying of objects and individual items. RFID is established since the Second World War for recognizing the friendly aircrafts, and it has taken the place of magnetic stripe cards in the 1990's (Xiao et al. 2007).

Technology of RFID is based on radio wave propagation operating in the ISM band. RFID includes a RFID-reader which is the receiver and a RFID tag which is the transmitter. RFID tags can be active or passive tag since the active tags are communicating with the RFID-reader continually but the passive tag is storing data until the reader connect to the tag for data acquisition.

Figure 2.1 is showing some of the RFID tags which has been applied for livestock (*GAO RFID*).

Figure 2.1: samples of active and passive RFID tags (*GAO RFID*)
(a): 125 kHz Low Frequency (LF) Animal Tracking Ear RFID Passive Tag (*GAO RFID*)
(b):Active RFID UHF –beacon Tag (*GAO RFID*) appropriate for tracking mobile assets
(c):A passive UHF (860 to 960 MHz) RFID Tag (*GAO RFID*)

2.2.2 Satellite Tracking

Satellite tracking is similar to RF tracking with distinction in operating frequency. Satellite tracking, consists of an orbiting satellite and receiver at ground station. It is applying one (as a minimum) satellite as the transponder and tags should communicate with it. Satellite network has been used for tracking various big animals such as caribou, elephants, eagles, and big fishes such as sea turtles, whales and sharks (Kerstetter, Polovina & Graves 2004).

The Array for Real-time Geotropic Oceanography (ARGOS) is a practical application case of satellite-based tracking system which covers several frequency ranges such as 1227MHz to 1228MHz, 1295MHz to 1296MHz, 1000MHz to 2000MHz. It was established in 1978 operated by CLS/Argos. ARGOS is used by many global research programs such as TOGA, TOPP, WOCE and automatic weather stations reports. ARGOS transmitters have been deployed on several marine mammals and turtles, and acts as the most important tool for tracking long distance movements of both coastal and oceanic species (*Worldwide tracking and environmental monitoring by Satellite*). ARGOS provides networks of satellites, and each satellite in a network picks up electronic signals from a transmitter on target (especially animals). Then, location of the animal is determined from analyzed data of all satellites in the network.

Global Positioning System (GPS), other example of satellite-based system, was developed in the 1980's and became fully operational in 1995 (*How Does GPS Work*). GPS system consists of a numbers of satellites placed in specific orbits around the earth, and a receiver on the earth surface. GPS receivers are implemented in mobile-phone, or specific GPS-Receiver equipments.

GPS satellites transmit two low power radio signals with L1 band (1227.60 MHz) and L2 band (1575.42 MHz) which it can pass through clouds, glass and plastics and travel by line of sight but will not propagate through most solid objects such as buildings and mountains (*How Does GPS Work*). Therefore, GPS tracking is applicable for outdoor and not indoor.

There are at least 24 GPS satellites operated by the U.S. Air Force, with the recognized location. GPS calculations are done at receivers based on Time-of-Arrival (TOA) and Trilateration method. Distance is measured from at least three satellites to apply Trilateration method for positioning receiver.

GPS accuracy depends on type of receiver; usually hand-held GPS units have about 10-20 meter accuracy. The higher accuracy, greater than 1 meter (*How Is The Accuracy Of A GPS Receiver Described*), is observed by Differential-GPS (DGPS) which requires an additional receiver fixed at a known location nearby. GPS is used for tracking of various items including animals in the form of collars, with about 2 meters accuracy of measurement.

GPS and ARGOS cover long distance communication but applicable for big animals. It is more expensive than radio frequency tracking equipments while RF tracking can be implemented by simpler circuits.

Table 2.1 compares RF with satellite tracking. From advantages and disadvantages, radio-frequency tracking is preferred for animal tracking because it is easier to implement and use, also it could be economically which is very important for biologists and research applications.

Table 2.1: Advantages and disadvantages of different tracking methods for Animals

	Advantages	Disadvantages
RF tracking	• Possibility to miniaturize the tags • Could use variety of frequency range • Simple design • Simple Use • Cost effective	• Short range coverage
Satellite Tracking	• Cover long distance communication • Higher accuracy	• Applicable just for the big animal • Costly • Not simply designed • Not simply implemented • Difficult to miniaturize the tags • Complicated data analyzing • Cannot be implemented on the small animals

2. 3 Localization Methods

Localizing target's coordinates, is used in various applications such as navigation systems, civil engineering mapping, fleet tracking, mobile tracking, animal tracking and etc. Localizing can be done by Trilateration or Triangulation methods. Trilateration localizing is based on distance measurement among the target and at least three recognized reference points while, in Triangulation the angle among the target towards a recognized point is measured.

2.3.1 Trilateration Method

Trilateration method is positioning a target point respect to one recognized point with knowing of at least three recognized coordinates and distance from those point to the target (Manolakis 1996; Chok et al. 2009). Figure 2.2 shows how Trilateration is localizing a target point. Three recognized reference coordinates are marked with S1, S2 and S3. Measured distances from target point to three references showed by r1, r2 and r3 and relative circles. Intersection of these three circles is the target point.

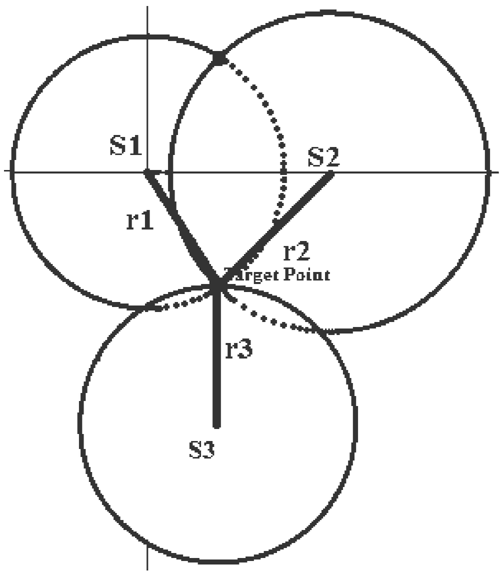

Figure 2.2: Trilateration Localization Method

Locating a point in 2-D plane requires measuring distance between the point and at least two known points. The fix points are known as the references nodes with the recognized coordinate. Although distances from two axes are enough for positioning, but in practice for better accuracy, distance measured from target to all three references.

Having three distances and three references' coordinate, then target's position is calculated by the following equation system:

$$\begin{cases}(x_t - x_1)^2 + (y_t - y_1)^2 = {r_1}^2 \\ (x_t - x_2)^2 + (y_t - y_2)^2 = {r_2}^2 \\ (x_t - x_3)^2 + (y_t - y_3)^2 = {r_3}^2\end{cases} \tag{2.1}$$

$(x_1, y_1), (x_2, y_2), (x_3, y_3)$ are the references' coordinate and (x_t, y_t) is target position. r_1, r_2, r_3 are three measured distance between target and the respective reference point. As positioning is relative, therefore one of the reference points is deemed as coordinate origin. If the first reference node is selected as the coordinate origin then equation (2.1) is simplified to equation (2.2):

$$\begin{cases}{x_t}^2 + {y_t}^2 = {r_1}^2 \\ (x_t - x_2)^2 + (y_t - y_2)^2 = {r_2}^2 \\ (x_t - x_3)^2 + (y_t - y_3)^2 = {r_3}^2\end{cases} \tag{2.2}$$

The above equation system is written from three circles with the radius of the measured distance and center of the reference points. Intersection between these three circles is calculated as target position. A solution for this equation system is through matrix method. Equation (2.1) should be written in matrix form like:

$$AT = B \tag{2.3}$$

T is the unknown values of target position in equation (2.2). ***A*** and ***B*** are define as the following:

$$A = \begin{bmatrix} 2(-x_3) & 2(-y_3) \\ 2(x_2 - x_3) & 2(y_2 - y_3) \end{bmatrix}, \qquad B = \begin{bmatrix} -{x_3}^2 - {y_3}^2 + {r_3}^2 - {r_1}^2 \\ {x_2}^2 - {x_3}^2 + {y_2}^2 - {y_3}^2 + {r_3}^2 - {r_2}^2 \end{bmatrix}$$

x_t and y_t are calculated by equation (2.4):

$$\begin{cases} x_t = -\frac{1}{2}\left(\frac{y_2\left(r_3{}^2 - x_3{}^2 - r_1{}^2\right) + y_3\left(r_1{}^2 - r_2{}^2 - y_2 + y_2{}^2 + x_2{}^2\right)}{x_3 y_2 - x_2 y_3}\right) \\ y_t = \sqrt{r_1{}^2 - x_t{}^2} \end{cases} \quad (2.4)$$

Calculated position by equation (2.4) is exactly the circles' intersection if three radii were accurately measured.

Offset error in horizontal or vertical alignments is dependent to that in which measurement error has occurred. If δ_1, δ_2, δ_3 suppose as the offset error of r_1, r_2, r_3 respectively then:

$$\begin{cases} r_{a1} = r_{m1} + \delta_1 \\ r_{a2} = r_{m2} + \delta_2 \\ r_{a3} = r_{m3} + \delta_3 \end{cases} \quad (2.5)$$

r_{a1}, r_{a2} and r_{a3} are three actual radiuses and r_{m1}, r_{m2}, r_{m3} are the relative measured radiuses. Substituting actual radiuses in equation (2.4) then:

$$\begin{cases} x'_t = -\frac{1}{2}\left(\frac{y_2\left((r_3+\delta_3)^2 - x_3{}^2 - (r_1+\delta_1)^2\right) + y_3\left((r_1+\delta_1)^2 - (r_2+\delta_2)^2 - y_2 + y_2{}^2 + x_2{}^2\right)}{x_3 y_2 - x_2 y_3}\right) \\ y'_t = \frac{1}{2}\left(\frac{x_2\left((r_3+\delta_3)^2 - (r_1+\delta_1)^2 - x_3{}^2 - y_3{}^2\right) + y_3\left(x_2{}^2 - y_2{}^2 + (r_1+\delta_1)^2 - (r_2+\delta_2)^2\right)}{x_3 y_2 - x_2 y_3}\right) \end{cases} \quad (2.6)$$

(x'_t, y'_t) is the calculated point which it might have $(\Delta x, \Delta y)$ offset error.

$$\begin{cases} \Delta x = x_t - x'_t \\ \Delta y = y_t - y'_t \end{cases} \quad (2.7)$$

Then:

$$\begin{cases} \Delta x = -\frac{1}{2}\left(\frac{\delta_1{}^2(y_3 - y_2) + 2r_1\delta_1(y_3 + y_2) - 2r_3\delta_3\, y_2 - y_3\left(\delta_2{}^2 + 2r_2\delta_2\right)}{x_3 y_2 - x_2 y_3}\right) \\ \Delta y = \frac{1}{2}\left(\frac{(y_3 - x_2)\left(\delta_1{}^2 + 2r_1\delta_1\right) + x_2\left(\delta_3{}^2 + 2r_3\delta_3\right) - y_3\left(\delta_2{}^2 + 2r_2\delta_2\right)}{x_3 y_2 - x_2 y_3}\right) \end{cases} \quad (2.8)$$

If equal error for all measurements:

$$\delta_1 = \delta_2 = \delta_3$$

Assuming δ_E as the maximum possibility of expected measurement error, to simplify the error then:

$$\delta_E = \delta_1 = \delta_2 = \delta_3$$

Equation (2.8) is simplified to equation (2.9):

$$\begin{cases} \Delta x = -\frac{1}{2}\langle\frac{-y_2\delta_E{}^2+2\delta_E(r_1[y_3+y_2]-r_3\, y_2-y_3r_2)}{x_3y_2-x_2y_3}\rangle \\ \Delta y = \quad \langle\frac{\delta_E{}^3(y_3[r_1-r_2]+x_2[r_3-r_1])}{x_3y_2-x_2y_3}\rangle \end{cases} \tag{2.9}$$

Equation (2.9) shows that positioning offset error is associated with references' coordinates, distance from target to references (radiuses) and occurred offset error (δ_E).

From previous works on Trilateration, least square and L-shaped (Maxim et al. 2008) are the methods to minimized the error during Trilateration positioning but both have limitations for the recognized coordinate selection.

2.3.2 Triangulation Method

Triangulation is a method of positioning which is based on angle measurements. It needs to measure two angles from two recognized point along the horizon. Triangulation is explained through Figure 2.3 seeing as the observer at point *A* measures the angle α and observer at point *B* does the same for β. Distance between (*l*) A and B should be known. The solution for calculating *C* coordinate is to calculate the intersection of two cords' equations of *AC* and *BC*.

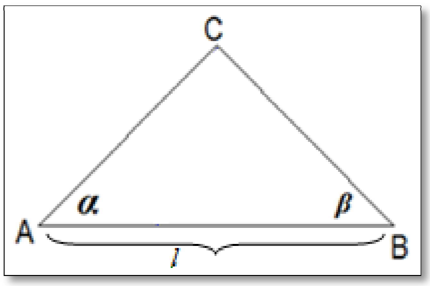

Figure 2.3: Triangulation localizing Method

2.3.3 Comparison of Trilateration and Triangulation

Trilateration have simpler mathematic and is easier to practically implement as Trilateration requires to measure distances but Triangulation need to measure two angles which needs more difficult technique. Trilateration often is preferred because of simpler methods available for remote distance measurement rather than angle (Chandra 2005; Zaniani, Shahar & Azid 2010).

Trilateration is widely used to determine position in 2-D or 3-D plane since 1995 till present (Manolakis 1996; Murphy & Hereman 1999; J B McKay & M Pachter 1997) .

Trilateration was studied for improvement and error correction during this research as a continuation from other improvement on Trilateration presented by Bahr (Bahr & Leonard 2007). Trilateration is broadly implemented with RSS based measurement although it is applied for GPS localization and has also carried out based on TOA range measurement.

2. 4 Review of Remote Distance Measurement Techniques

Scale and accuracy of distance measurement are the most important factors to select the measurement method, as well as cost. It is also related to expected accuracy of tracking. RSS and TOA, the basic methods of range measurement, can be performed with lower price which are also implemented through this research and presented and reviewed in the following. Some applications including animal tracking are also presented.

2.4.1 RSS Range Measurement

Received Signal Strength (RSS) measurement is clearly a method that includes measuring the signal strength at receiver. RSS is implemented by at least two stations (a transmitter, a receiver) and received signal strength at receiver is compared with broadcasted signal from transmitter to find out the strength reduction through the path. Signal strength reduction is also described as power loss and depends on distance and other factors between transponders.

Available studies on RSS range measurement in (Lakshmanan et al. 2009; Shirahama & Ohtsuki 2008) contains the study of power loss through the path. Practical path loss models, dedicated for special design with its restrictions such as limited frequency band for each model and so on.

RSS range measurement predicts distance versus losses through the path. Path loss depends on different factors and aspects of the path. Losses through space known as Free-Space-Loss (FSL) is the power loss of an RF signal propagating through space expressed in dB and depends on distance between transmitting and receiving antennas, LOS clearance between the receiving and transmitting antennas (Kraus 1950).

$$\frac{P_R}{P_T} = G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \ , \ Loss = \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (2.13)$$

where P_R is receiving power strength, P_T is transmitting power strength, G_R is receiving antenna gain, G_T is transmitting antenna gain, d is path length and λ is the wavelength and *Loss* is power loss.

It is written in form of dB for isotropic antenna by the following equation:

$$Loss = 32.4 + 20\log(f) + 20\log(d) - 10\log(G_T) - 10\log(G_R) \qquad (2.14)$$

where *Loss* is the losses through the space in dB, *f* is the carrier frequency in MHz, *d* is distance in km, G_T and G_R is transmitter and receiver antennas power gain in dBi.

Loss for isotropic antenna is simplified to following equation where d is in meter:

$$Loss_{433} = 32.4 + 20\log(f) + 20\ log\ (d) \tag{2.15}$$

2.4.2 TOA Range Measurement

Time-Of-Arrival (TOA) is other method for distance measurement and applied in GPS for outdoor distance measurement by means of the accurate clock in GPS receivers.

$$d = v.T \tag{2.16}$$

where *v* is velocity of signal through the path, *T* is time of signal arriving to the receiver and *d* is calculated distance.

Velocity of electromagnetic waves considered as speed of light through the vacuum (*c*) therefore, the above equation of distance is accurate for free space and LOS link. Otherwise, with existence of obstacle or non-LOS links, the speed of propagation will change. TOA is widely used for distance measurement with correlated accuracy through various researches (Alavi & Pahlavan 2006; Alsindi, Alavi & Pahlavan 2009) .

2. 5 Path Loss Prediction Review

Path loss prediction is an important part of wireless and telecommunication applications. Path loss depends on several factors such as distance, medium of propagation, presence or absence of barrier through the path, type of weather condition and so on. All these factors affect the propagated wave and produce different losses such as absorption, scattering and reflection. Also some other factors such as phase canceling, wind effect and thermal noise that produce extra losses are discussed in the following.

2.5.1 Absorption

A portion of wave is absorbed by medium or object which the electromagnetic wave is coming across with. Object's size and nature which are known as the attenuation factor, establish the absorption loss (Cheng 1989).

$$A_a = e^{-\alpha z} \tag{2.17}$$

where as A_a is the amplitude attenuation in (dB), α is the attenuation constant in (Np/m) and z is the distance in (m) clarifying by depth of the obstacle.

$$\gamma = \alpha + j\beta \tag{2.18}$$

where γ is the complex propagation constant, β is the phase constant and:

$$\gamma = j\omega\sqrt{\mu\varepsilon}\sqrt{\left(1 + \frac{\sigma}{j\omega\varepsilon}\right)} \tag{2.19}$$

where $\alpha = Re\{\gamma\}$

By equation (2.17) and (2.19), absorption is dependent on distance, frequency and the object's permittivity (ε) and permeability (μ). As permittivity and permeability are also dependent to frequency and temperature, therefore absorption by different objects, if not impossible but it is very difficult to calculate.

2.5.2 Reflection

Reflection from a surface or barrier is due to the impedance mismatch between transmission line and barrier. Calculating the ratio of reflected signal requires the impedance value of both propagation medium and object.

Considering Z_1 as the free space impedance (376.73 ohm) and Z_o as the obstacle impedance, then reflected ratio is calculated by equation (2.20):

$$L_r = 20\ log_{10}\left|\frac{Z_1 - Z_2}{Z_1 + Z_2}\right| = 10\ \ log_{10}\frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2} \tag{2.20}$$

Calculating the reflection ratio seems to be impossible as Z_o depends on permeability and permittivity of the obstacle.

2.5.3 Scattering

In the collision of wave and two objects, in addition to the common boundary reflection, refraction and mode changes, wave is scattered around the border. If interference waves are equal phase and elastic waves scattered around the object border, and resonance happens in the spectrum of scattered waves as the energy loss (peak) appears (Torrico & Bertoni 1998). Scattering loss, caused by barrier through the path looks impossible to be estimated theoretically, especially for vegetation with different size and shapes. As the scattered wave is related to incident angle of wave radiant, hence wind may also affect the scattering loss by moving the leaves.

2.5.4 Phase Cancelling

Sometimes there is no obstacle along the path but as the antenna height is too short ground surface diffract the signal along the Fresnel radius. In fact, phase cancelling is a type of diffraction in the area of Fresnel zone which is an elliptical region surrounding the line-of-sight path between the transmitter and receiver antennas. Radius of this ellipsis is called 'Fresnel-Radius' (Fr). Two antennas having line-of-sight (LOS) link, their height must be greater than 60% of 1^{st} Fresnel radius or greater than 60% of any other *odd* radiuses. The *even* Fr is where maximum phase cancelling happens unlike the *odd* radiuses. The "*odd*" Fr is more constructive since the reflection from the roof of an obstruction will reach the receiver with the same phase as the main beam. The formula for calculating the Fresnel radius is as follows:

$$F_{rn} = \sqrt{\frac{d_1 d_2}{(d_1+d_2)} \, .n.\lambda} \tag{2.21}$$

n is Fresnel Radius Number; 1,2,3,.....; λ is Wavelength in meters, d_1 and d_2 and distance between two antenna apart from barrier, and are equal and half of the end-to-end path length if no obstacle presence through the path.

The spheroid area within two antennas called *Fresnel zone* (Ghasemi, Abedi & Ghasemi 2011) . The certain part of the wave energy is communicated within an area with certain radius called the *1st Fresnel radius*. However, interfering obstacles in the Fresnel zone, the transmitted energy becomes weaker. Minimum antenna height for LOS link to conform FSL is the height of fist Fresnel Radius that is no interfering of ground and any other obstacle. This is graphically presented through Figure 2.4.

First Fresnel radius for distance *D* is calculated by equation (2.22) where *f* in *GHz* and *D* is in *Km* and *1^{st} Fr* is radius of first Fresnel zone in meter (Ghasemi, Abedi & Ghasemi 2011).

$$1^{st}\mathrm{Fr} = 17.32\sqrt{\frac{D}{4f}} \tag{2.22}$$

1^{st} Fr for 30 distance and 433 MHz carrier frequency is calculated:

$$r = 17.32\sqrt{\frac{0.03}{4 * 0.433}} \approx 2.28\,m$$

Therefore, 2.3 m antenna height is selected during experiments up to around 30m distance among the transponders, in order to fulfill the 1st Fr and communicate the certain part of the wave energy and minimize the losses.

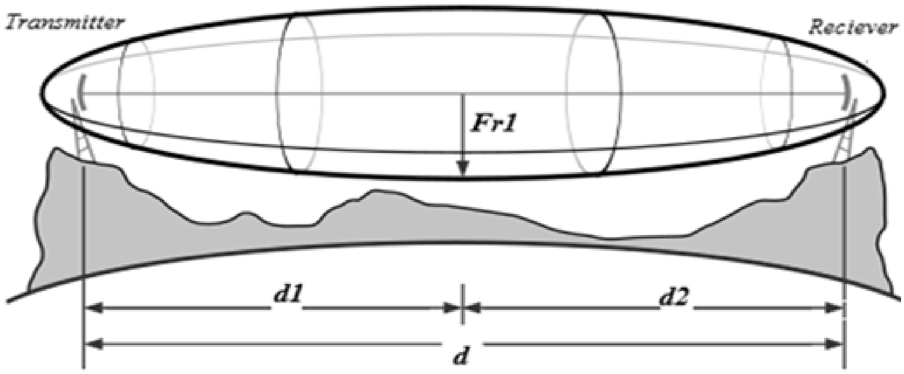

Figure 2.4: Fresnel Zone Sphere-Shaped Area (Ghasemi, Abedi & Ghasemi 2011)

Fresnel radius effect is practically analyzed and discussed in the next chapter. From theory of *Fresnel zone*, a range of distortion is expected rather than FSL through the path related to distance between two antennas and antennas' height. This extra losses might be observed in the locations where antenna height is equal to one of the even Fresnel radiuses (Fr_2, Fr_4, Fr_6,...) or $0.6Fr_n$ (n is an even number).

2.5.5 Wind Effect

Wind variation is a strong factor to alter the losses through an open area. As wind contains certain amount of energy correlated with the wind velocity (Kraus 1950) therefore, it can affect the electromagnetic waves. Power density of wind is calculated by (2.23):

$$\frac{P}{A} = \frac{1}{2}\rho V^3 \quad (2.23)$$

Where P is power contained in the wind (watt), A is the exposure area of wind (ft^2 or m^2), ρ is the density of air (about 0.07654 Ibm/ft^3 or 1.23 kg/m^2) and V is the wind velocity (ft/s or mile/hr[mph] or km/hr & etc).

Clearly, the wind power is directly proportional to cube of wind velocity (V^3) and small changes in the wind velocity yields large variation in power.

In addition, the electromagnetic wave's energy (E) calculates by:

$$E = h\vartheta \quad (2.24)$$

Where E is the wave energy (Joule), h is the Plank constant = 6.626×10^{-34}(J/s), ϑ is the wave frequency (Hz). The wave's energy per second is the power of wave in watt and it can compare with the transmitter output power.

Wind also resulting sharp drop in the received signal strength since shaking antenna or changing the antenna direction.

2.5.6 Thermal Noise

Thermal noise is due to the temperature variation and generates by random thermal motions of electrons according to ground radiation, atmospheric attenuation, and other sources {Kraus, 1950 #3}. The strength of thermal noise is calculated by equation (2.26) in Watt where K is the Boltzman constant and equals to 1.38×10^{-23} (J/Kelvin), T_{sys} is system temperature (Kelvin), Δv is the frequency interval or bandwidth (hertz) and P_{Noise} is the noise power in Watt.

$$P_{Noise} = KT_{sys}\Delta v \quad (2.26)$$

It can be considered as the noise density by equation (2.27), where P_0 is the noise density (watt/hertz).

$$P_0 = KT_{sys} \quad (2.27)$$

Considering antenna noise temperature (Seybold 2005), equation (2.26) can be written as:

$$P_{Noise} = K(T_{sys} + T_A)\Delta v \quad (2.28)$$

Antenna noise temperature associates with sources such as galactic radiation, earth heating, the sun, electrical devices and the antenna itself (Seybold 2005).

The level of the sun's contribution depends on wave frequency and is given by:

$$T_A = 3.468\, F\, \lambda^2 10^{(G/10)}\ v \quad (2.29)$$

where F is the solar flux, λ is wavelength; G is the gain of the antenna (dB).

Consequently temperature noise is bigger for higher frequencies but reducible through narrow bandwidth and using lower gain antenna. Temperature and wind effect are two noise factors which are not included in standard telecommunication propagation models. Considering the noise effect demands to look at statistical noise model for future work.

2.5.7 Available Practical Propagation Models

Theoretically, calculating all types of losses through the path, if not impossible but is very difficult. Therefore, path loss had practically studied since 1960 for different environments and conditions. Here, in this study, some available practical models are reviewed for LOS and non-LOS cases.

2. 5.7.1 Practical Path Loss Models through LOS

In the case of Line of Sight (LOS), the main part of power loss is calculated from free space power loss (equation (2.12) but it is not accurately calculated in theory, since the wavelength depends on the wave velocity and wave velocity is