

Wright State University  
**CORE Scholar**

---

[Browse all Theses and Dissertations](#)

[Theses and Dissertations](#)

---

2009

## Localization and Surveillance using Wireless Sensor Network and Pan/Tilt Camera

Pratikkumar U. Desai  
*Wright State University*

Follow this and additional works at: [https://corescholar.libraries.wright.edu/etd\\_all](https://corescholar.libraries.wright.edu/etd_all)



Part of the [Electrical and Computer Engineering Commons](#)

---

### Repository Citation

Desai, Pratikkumar U., "Localization and Surveillance using Wireless Sensor Network and Pan/Tilt Camera" (2009). *Browse all Theses and Dissertations*. 928.  
[https://corescholar.libraries.wright.edu/etd\\_all/928](https://corescholar.libraries.wright.edu/etd_all/928)

This Thesis is brought to you for free and open access by the Theses and Dissertations at CORE Scholar. It has been accepted for inclusion in Browse all Theses and Dissertations by an authorized administrator of CORE Scholar. For more information, please contact [library-corescholar@wright.edu](mailto:library-corescholar@wright.edu).

# Localization and Surveillance using Wireless Sensor Network and Pan/Tilt Camera

A thesis submitted in partial fulfilment  
of the requirements for the degree of  
Master of Science in Engineering

By

PRATIKKUMAR U. DESAI  
B.E., South Gujarat University, India, 2006

2009  
Wright State University  
Dayton, Ohio 45435-0001

WRIGHT STATE UNIVERSITY  
SCHOOL OF GRADUATE STUDIES

March 20, 2009

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY PRATIKKUMAR UMESHBHAI DESAI ENTITLED Localization And Surveillance Using Wireless Sensor Network And Pan/Tilt Camera BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Engineering.

---

Kuldip S. Rattan, Ph. D.  
Thesis Director

---

Kefu Xue, Ph. D.  
Department Chair

Committee on  
Final Examination

---

Kuldip S. Rattan, Ph. D.

---

Xiaodong Zhang, Ph. D.

---

Devert W. Wicker, Ph. D.

---

Joseph F. Thomas, Jr., Ph.D.  
Dean, School of Graduate Studies

## ABSTRACT

Desai, Pratikkumar. M.S. Egr. Department of Electrical Engineering, Wright State University, 2009. Localization and Surveillance using Wireless Sensor Network and Pan-Tilt Camera.

The ever growing challenges in hostile environments, health care and warzone require accurate indoor localization and surveillance. The de facto localization technique using GPS has poor indoor performance due to the complexity of the indoor environment. Other Radio frequency based indoor localization techniques are unable of accurate localization due to multipath fading.

In this thesis, a system consisting of Cricket wireless sensor motes, a camera and a Pan/Tilt gimbal is proposed to solve the indoor localization and surveillance problems. The system is easy to deploy, is cost effective and gives accurate results. The Crickets motes use the Time Difference of Arrival (TDoA) between the RF and the ultrasound signals to estimate the distance of the object. Multilateration is used to calculate the position of the object in the reference beacon coordinate system. This position is then transformed to the object coordinate system to calculate the pan and tilt angles of the gimbal which are then used to direct the camera to the object. The programming language JAVA was used to develop a GUI program to interface the gimbal, the camera and the Cricket motes.

The localization and tracking of the object was successfully carried out in the laboratory. The accuracy of the system was tested using a laser pointer mounted on top of the camera and was shown that the system tracked the object with negligible error.

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Related work . . . . .	1
1.1.1	GPS (Global Positioning System) . . . . .	2
1.1.2	Active Badge system . . . . .	2
1.1.3	RADAR: An In-Building RF-based User Location and Tracking System . . . . .	3
1.1.4	Active Bat system . . . . .	3
1.1.5	Object tracking with multiple cameras . . . . .	4
1.1.6	RFID Radar . . . . .	4
1.2	Motivation . . . . .	5
1.3	Wireless sensor network . . . . .	5
1.3.1	Characteristics . . . . .	7
1.3.2	Applications . . . . .	7
1.4	Infrastructure used . . . . .	8
1.5	Software tools . . . . .	9
1.6	Thesis Organization . . . . .	10
<b>2</b>	<b>Cricket notes</b>	<b>11</b>
2.1	MICA series . . . . .	11
2.1.1	MICA2 motes . . . . .	12
2.1.2	MICA2DOT motes . . . . .	13
2.1.3	MICAz motes . . . . .	14

2.2	Cricket Overview . . . . .	14
2.3	Cricket System architecture . . . . .	16
2.4	Cricket Software architecture . . . . .	17
2.4.1	TinyOs and Cricket firmware . . . . .	19
2.4.2	Software tools at Host end . . . . .	19
2.5	Chapter Summary . . . . .	20
<b>3</b>	<b>Distance Estimation and Localization</b>	<b>21</b>
3.1	Distance Estimation Techniques . . . . .	21
3.1.1	Experiments for Distance Estimation using MICAz motes . . . . .	23
3.1.2	Distance Estimation using Cricket motes . . . . .	24
3.2	Location Estimation Techniques . . . . .	26
3.2.1	Experimental Setup for location estimation . . . . .	26
3.2.2	Position Estimation . . . . .	26
3.2.3	Orientation Estimation . . . . .	29
3.3	Chapter summary . . . . .	30
<b>4</b>	<b>Surveillance and Transformation</b>	<b>31</b>
4.1	Surveillance Camera assembly . . . . .	31
4.1.1	Pan-Tilt Gimbal module . . . . .	31
4.1.2	X10 Wireless camera system . . . . .	32
4.2	Co-ordinate Systems and Rotation . . . . .	34
4.3	Transformation Mathematics . . . . .	35
4.4	Summary . . . . .	39
<b>5</b>	<b>Results and Possible Applications</b>	<b>40</b>
5.1	Results . . . . .	40
5.2	Possible Application . . . . .	44
5.2.1	Army . . . . .	44
5.2.2	Home Appliances . . . . .	44
5.2.3	Health Care . . . . .	44

5.2.4	Environment Monitoring . . . . .	45
<b>6</b>	<b>Summary and Conclusion</b>	<b>46</b>
6.1	Summary and Conclusion . . . . .	46
6.2	Challenges and Future Work . . . . .	47

# List of Figures

1.1	Block Diagram of the system . . . . .	6
1.2	Mica2Dot wireless motes from Crossbow technology . . . . .	7
2.1	MICA2 wireless sensor mote and Block diagram . . . . .	12
2.2	MICA2DOT wireless sensor mote and Block diagram . . . . .	13
2.3	MICAz wireless sensor mote and Block diagram . . . . .	14
2.4	Cricket hardware components . . . . .	15
2.5	System architecture of The Cricket motes . . . . .	16
2.6	Software architecture of The Cricket motes . . . . .	18
3.1	Simple iteration Approach . . . . .	22
3.2	Simple angulation Approach . . . . .	23
3.3	Time difference of arrival approach for distance estimation using cricket motes . . . . .	25
3.4	Experimental setup for the position estimation . . . . .	27
3.5	A simple orientation estimation technique . . . . .	30
4.1	Pan-Tilt Gimbal and X10 camera assembly . . . . .	32
4.2	Phidget Advanced servo Controller [25]. . . . .	32
4.3	VR42A Audio Video receiver for X10 camera System[24]. . . . .	33
4.4	Pan and Tilt rotation of the Co-ordinate system . . . . .	34
4.5	Co-ordinate systems and rotations before Origin transformation . . . . .	35
4.6	Co-ordinate systems and rotations after Origin transformation from the beacon to the camera . . . . .	36



5.1	Actual distance vs Error in distance estimation . . . . .	41
-----	---	----

# List of Tables

5.1	Comparison of Actual position and the error between the actual position and the position obtained from the Cricket system. . . . .	42
5.2	Actual position and the error between position and the position pointed by laser system. . . . .	43

## ACKNOWLEDGEMENTS

I would foremost like to thank my advisor and mentor, Dr. Kuldip Rattan, who has not only been a great professor but also a good friend, helping me academically and also providing necessary components for this research. It was his guidance and suggestions that kept me in the right track up to the completion of this research and the review of the manuscript. I would like to thank Dr. Erick Blasch for providing valuable suggestions and guidance.

Finally, I am forever indebted to my parents and Sachi for their understanding, endless patience, love and encouragement when it was most required. I would also like to thank my friend Jasmin Soni, who found time from his busy schedule to help me out in the experimental setup.

# 1

## Introduction

Think about a future scenario in which a group of terrorist are hiding with hostages in a metropolitan building and their hideout place is unknown to the military forces. It is too dangerous to send soldiers in the building without knowledge of the accurate terrorist positions.

Consider one more scenario where a wheel chaired person living alone in a house gets some kind of physical trauma and unable to move anywhere. The physical location and even the type of attack are unknown. In this case it is very difficult to send appropriate help without awareness of the location or the type of the problem. This kind of incidents occur in day to day life and can be avoided by implementing a large scale network of tiny sensors and utilizing the network to locate the object.

The goal of this thesis is to attach tiny sensor motes on the ceiling, create a Wireless Sensor Network to locate moving an object inside the building and use a Pan/Tilt gimbal camera system to actively survey the object.

### 1.1 Related work

A lot of research had been done in the field of localization and surveillance. Some of them are described below.

### 1.1.1 GPS (Global Positioning System)

From years, GPS has been a popular tool for outdoor localization. GPS system consists of 27 to 31 satellites orbiting around earth. Started as a military project called NAVSTAR-GPS, GPS was introduced to public domain in 1983. Since then, GPS is being used in localization, tracking and navigation applications in different instruments such as cell phones, cars and even airplanes. GPS enabled instrument generally consist of a GPS receiver, connected to at least four satellites to solve three unknown position variables and time. In GPS system time is also a unknown variable because GPS satellites are synchronized with atomic clocks where as GPS receivers are not[13].

In various outdoor environmental conditions, GPS position estimation has accuracy of 5 to 20 meters. A new technology called Differential GPS can give accuracy of less than a meter. The GPS system can not estimate the position in indoor application because the unobstructed Line-Of-Sight (LOS) is not present. Even multiple factors like multipath propagation, shadowing effects, surrounding objects velocity, mobile relative velocity, cross correlation can produce significant effects on position results[14]. In this case, we need an indoor localization system which is as accurate as GPS and is also globally available.

### 1.1.2 Active Badge system

A Pioneer of indoor location system, active badge system uses infrared badges worn by the office staff. These active badges transmit infrared signals with unique *id* to the centralized location system. The centralized location system is connected to office wide network of sensor which is responsible for getting infrared signals from badges. This information from sensors is stored in a database for each unique *id*. The Office walls being natural boundary of the infrared signals, receiver can identify the badge inside the office room. This system has the ability to localize object inside an office room but without position estimation, it is very difficult to estimate accurate location.[15]

### 1.1.3 RADAR: An In-Building RF-based User Location and Tracking System

Researchers at Microsoft research lab have developed an indoor RADAR system which uses RF signal to localize and track users inside building. The RADAR system uses radio-frequency signal strength indicator (RSSI) to estimate distance. This system operates on empirical method, which is more accurate in terms of position estimation, and simple signal propagation method, which is easier in deployment[1].

The RADAR system collects empirical signal strength data using multiple base stations to provide overlapping coverage. These distance estimations are then triangulated to locate user. Using empirical method RADAR is able to get median resolution of 2-3 meters.

### 1.1.4 Active Bat system

Active Bat is a centralized location technique like active badge system but the only difference is the use of RF and ultrasound signals instead of infrared signals[16]. Similar to the active badge system, the active bat uses small wireless transmitter tags attached with objects within the system. These RF transmitters, which consists of RF transceiver, microcontroller and ultrasonic transmitter, periodically transmit RF signal with their unique *id* to the RF receivers. The RF receivers are mounted on the ceiling in array formation with ideal distance of 1.2 meters apart. These RF receivers are connected with centralized RF base station via serial data network, which is responsible for processing the data acquired from each RF receivers. The RF base station is connected to a computer responsible for all data analysis and processing.

To localize a object, the RF base station periodically transmit signal to all objects mounted with RF transmitter through RF transceiver mounted on ceiling. After receiving RF signal, object transmits ultrasound pulse to RF receivers, which also include a ultrasound receiver, detect the ultrasound signal and send the readings to the RF base station. The RF base station calculates distance using time difference between RF signal and ultrasound signal.

Cricket motes used in this thesis work on the same principle of distance calculation but the Cricket mote is a decentralized system and does not require a base station to calculate position of the object.

### 1.1.5 Object tracking with multiple cameras

Research is being carried out in to use Pan/Tilt/Zoom camera as sensors instead of using them as passive cameras. Growth in computer processing power has enabled the complex image processing on smaller devices. In this system, moving object is tracked by camera using image processing algorithms. Pan/Tilt/Zoom camera track direction of the target movement and move with the moving object[20]. Building contains a network of multiple cameras connected with base station and camera hand over the target position to the respective camera while the target is in transition from one room to another.

As this approach uses image processing, it can fail when target color is not discriminative. This approach can just monitor one moving object in premises but it can not be used in environment with multiple moving objects. This approach is vulnerable in military application or patient monitoring system where we need position of the specific target.

### 1.1.6 RFID Radar

In contrast to wireless sensor node, RFID (Radio Frequency *ID*) tags are passive and not able to communicate between each other. A company from South Africa, Trolley Scan (Pty) Ltd, has developed RFID-radar to accurately localize RFID tags[19]. RFID-radar uses combination of measured distance and angle of arrival to find position of the tag. The distance is determined by measuring path length for signals travelling from tag to the radar. The angle of arrival is calculated by comparing signals arriving at two identical receivers with closely spaced antennas. The RFID-radar is able to achieve resolution of 0.5 meter in distance and 1 degree in angle of arrival estimation.

## 1.2 Motivation

Technologies mentioned above are not accurate enough to localize an indoor object and cannot be used for precise surveillance using the Pan/Tilt camera. As a part of a localization project, Researchers at MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) developed 'Cricket' mote which can locate object using the radio and the ultrasonic signals. The Cricket motes are modified version of MICA2 mote by Crossbow technology. Development of the Cricket mote has enabled accurate indoor localization. Because of their tiny size they can be mounted on any object such as an autonomous robot , a wheelchair and a soldier. Miniature size and precise localization are main motivations to use the Cricket mote for the localization application.

It is hard to track and identify specific moving object in congested area using cameras. It is even harder to track an object if it is moving from one room to another, with different cameras. On the other hand, it is possible to use camera system as slave system and move them using their Pan/Tilt angles for the position derived from master system of the Cricket wireless sensor network.

Figure 1.1 illustrates the concept of the entire thesis. The thesis can be divided in three main blocks - a localization module using Cricket motes, a host computer to calculate location and transformation and a camera system with Pan/Tilt Gimbal for surveillance.

## 1.3 Wireless sensor network

In the past,the wired sensor network were used in the factory control and automation system. An exponential growth in wireless communication techniques has made it possible for wireless control and automation system on factory floor where systems are distance apart and it is very costly to established and maintain wired control system.

A wireless sensor network can be described as a network of miniature wireless



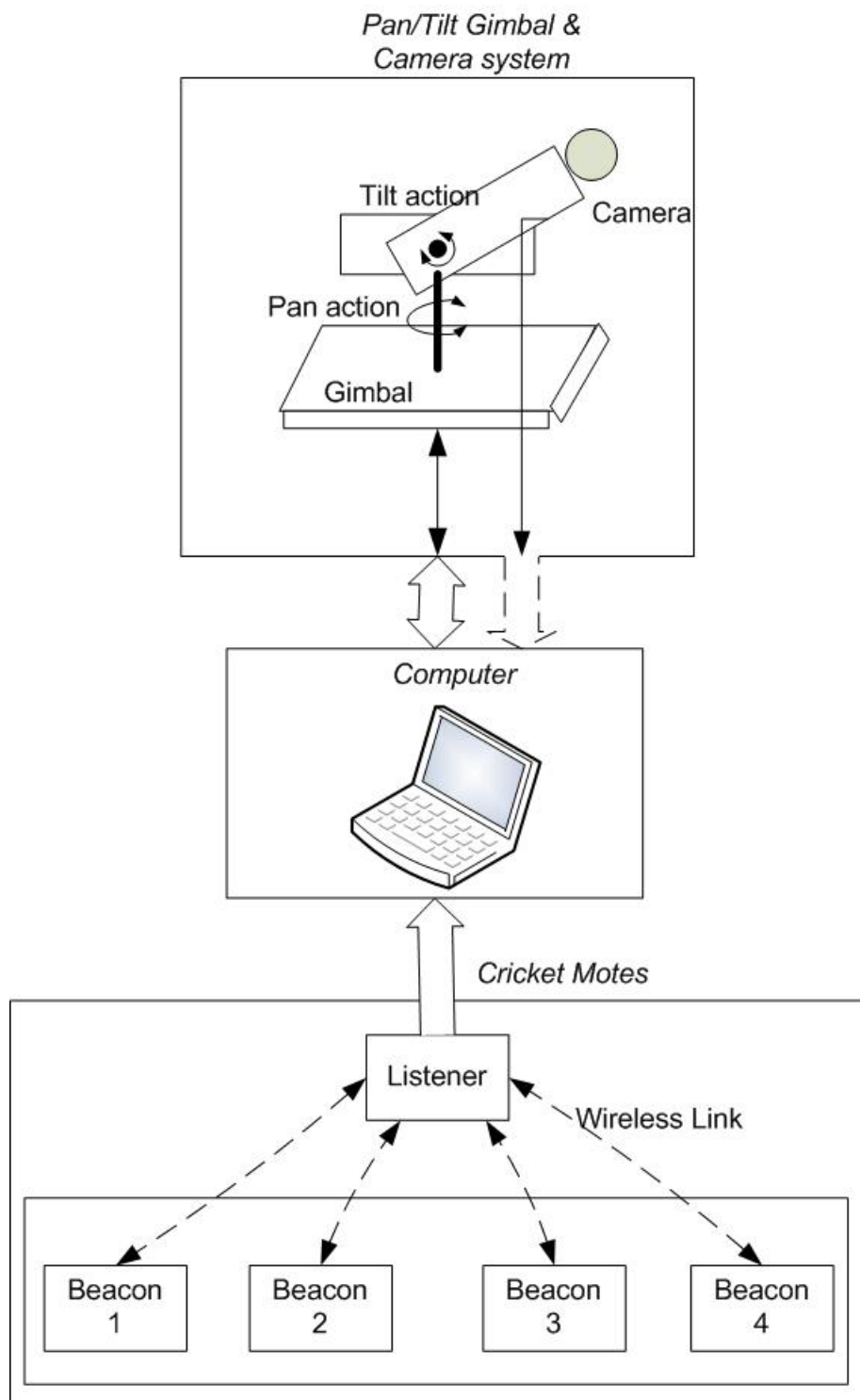


Figure 1.1: Block Diagram of the system

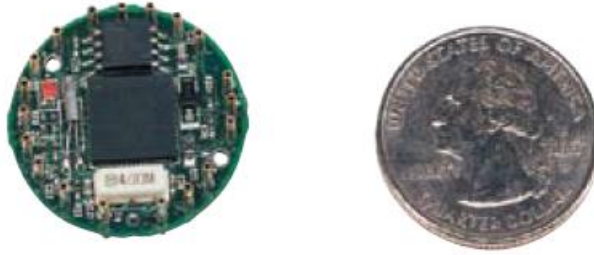


Figure 1.2: Mica2Dot wireless motes from Crossbow technology

autonomous devices, called motes, embedded with sensors to monitor environmental conditions such as temperature, sound, pressure etc. These motes are also capable of active inter communication with inbuilt radio transmitter and receiver.

### 1.3.1 Characteristics

Wireless sensor network have unique characteristics such as,

- Highly energy constrained
- Self-organizing and self-healing
- Scalability and adaptability
- Security and privacy
- Mobility of nodes

### 1.3.2 Applications

Because of the characteristics mentioned above, the wireless sensor network is being used in various application such as monitoring, tracking, and controlling. Some of the major usages of wireless sensor network are as follow:

- Monitoring and controlling factories, offices, etc.
- Detection and tracking of enemy vehicles

- Health care
- Tracking wildfire
- Tracking endangered species
- Habitat monitoring and sensing
- Localization

This thesis is developed around localization application of wireless sensor network. Description of localization and tracking is detailed in chapter 4.

## 1.4 Infrastructure used

The experiments in this thesis are performed using the Cricket motes and a custom Pan/Tilt gimbal camera system. This section gives a brief overview of the major components used. The Cricket motes and Gimbal assembly are described in Chapters 2 and 4, respectively.

- **Cricket motes:**

For the localization application, five Cricket motes manufactured by XBOW Inc are used. Four of them are used as beacon motes, mounted on the ceiling and one as a listener or mobile mote. This Cricket system functions as heart of the whole experiment. Chapter 2 gives a detailed description of the Cricket motes.

- **Pan/Tilt Gimbal:**

Two Hitec HS-422 servo motors and a mounting kit are used in the assembly of Pan/Tilt gimbal system. This gimbal is used as a mounting base for the surveillance camera.

- **Phidget servo controller:**

8 channel Phidget advanced servo motor controller is used to interface both servo motors with the host computer. The connection from the host computer to the controller was established via a Universal serial bus (USB) cable.

- **X10 surveillance camera:**

X10 wireless camera is used for surveillance purpose. Mounted on the gimbal, X10 transmits video signal via wireless transmitter to the computer. At the computer end, the wireless receiver, connected with A/V to the USB cable, convert received video signal in to computer accessible format. It is not necessary that the computer connected with X10 receiver should be the computer connected with servo controller and cricket mote, Since the computer is used in the passive monitoring mode.

## 1.5 Software tools

Java and TinyOs are the main software used during development of the thesis. This section gives an overview of the Java APIs and software tools used in this thesis. It also include a brief description of Java GUI (Graphical User Interface) developed. A detailed description of the software tool and its working are provided in Chapter 4.

- **TinyOs:**

Tinyos is the operating system for Cricket motes and uses nesC for mote programming.

- **ClientLib Java API:**

Written in java, ClientLib API provides access of localization reading from Cricket motes to a computer.

- **Phidget Java API:**

Phidget API is responsible for interfacing of servo motor controller with the computer.

- **Application User Interface:**

User interface created using Java swing deal with Phidget API and ClientLib API for camera surveillance.

## **1.6 Thesis Organization**

The remainder of the thesis is organized as follows. Chapter 2 overviews the system architecture and the working of Cricket motes. Chapter 3 describes different position estimation and localization techniques used in the thesis. Chapter 4 explains the Pan/Tilt gimbal mechanism ,the Co-ordinate Systems and Rotation . This chapter also gives a detailed description of the surveillance algorithm and transformation mathematics. Chapter 5 summarizes the results obtained and possible application using the introduced system. Chapter 6 concludes the thesis along with directions for future work.

## 2

# Cricket motes

Basically the wireless sensor network consist of small wireless beacons also called motes. Researchers at Berkeley NEST(Network Embedded Systems Technology) laboratory first coined the term 'mote'. These motes are made up of micro-controller, transceiver, external memory, power source and sometimes one or more sensors.

The basic idea behind creating sensor motes is to eliminate human involvement in gathering information and to create a smart environment based on the data collected from sensors. The IRIS, MICA series, iMote series, eko and Telos series motes are commercially available motes. MICA series motes are among the most popular one for low power applications and Cricket mote is a variant of MICA2 mote specifically designed for localization application.

This chapter includes brief introduction and architecture of motes used during development of the thesis. Section 2.1 describes the basic functionalities of MICA series motes and sections 2.2 - 2.4 used to describe the Cricket motes, the main wireless sensor platform used in this thesis.

### 2.1 MICA series

MICA series motes are developed and manufactured by crossbow technologies along with Telos and Imote series motes. The MICA, MICA2DOT, MICA2 and MICAz are the motes developed in MICA series. Among them, MICA2DOT, MICA2 and MICAz are the 3rd generation sensor motes used as wireless platform for smart sensors.

MICA series motes are designed specifically for deeply embedded Sensor Network and ideally have more than a year of life span using sleep mode. These motes are also designed to be programmed remotely for already established networks. MICA series motes are capable of communication with every node in network as router capability. These motes use the base station as a aggregation point for sensor network data onto computer platform. Crossbow technologies also manufacture base stations compatible with MICA series motes. These base stations have serial, USB or Ethernet interface for data communication. They are also used to burn program on the flash memory of the motes.

MICA series motes are equipped with standard I/O expansion connector. Crossbow technologies also offers variety of sensor board, data acquisition boards and gateways which can be connected to motes using expansion connector. These sensor boards include different types of sensors for ambient light, barometric pressure, GPS, magnetic field, sound, photo-sensitive light, photo resistor, humidity and temperature.

### 2.1.1 MICA2 motes

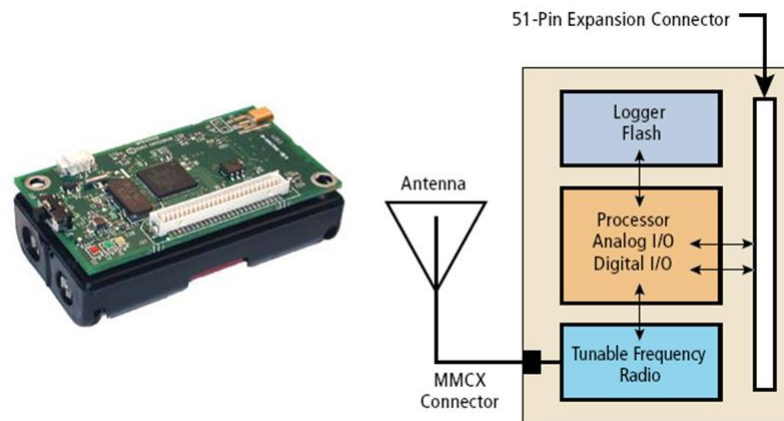


Figure 2.1: MICA2 wireless sensor mote and Block diagram

Figure 2.1 gives a detail of block diagram of MICA2 mote also called as MPR400.

MICA2 provides core architecture for all third generation motes of the series. The MICA2DOT and Cricket are the size and location specific variant of MICA2, respectively. MICAz shares common core architecture with MICA2, just not the wireless communication module. MICA2 uses 868/916 MHz ISM band multichannel transceiver for radio communication between motes. The core architecture of MICA2 is same as of Cricket and is described later in this chapter.

MICA2 motes widely used in application such as security monitoring, surveillance of a field and remote data logging. Due to its low data rate (38.4 kbps) MICA2 are not preferred in video or audio data gathering.

### 2.1.2 MICA2DOT motes

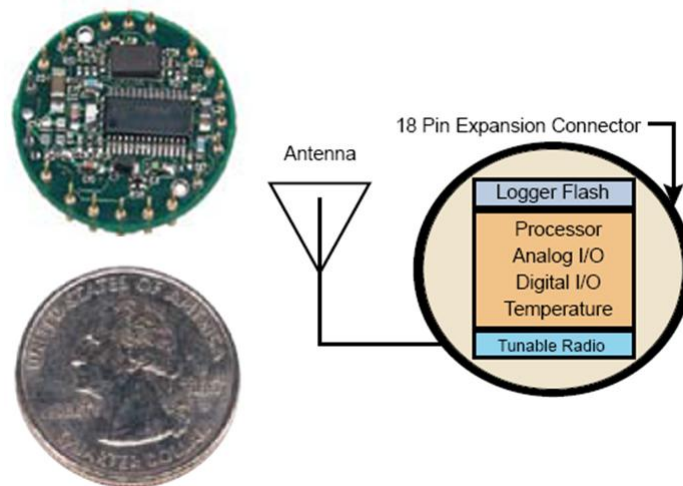


Figure 2.2: MICA2DOT wireless sensor mote and Block diagram

Figure 2.2 shows that MICA2DOT is a quarter sized MICA2 mote which is 25mm in diameter. MICA2DOT motes are equipped with onboard temperature sensor, battery monitor and LED which makes it suitable for temperature and environmental monitoring for deeply embedded sensor network.

Chapter 1 described the research going on with RFID tags. Because of its reduced size, MICA2DOT can be used as a smart, active 2-way tag instead of a passive RFID



tag, for localization application.

### 2.1.3 MICAz motes

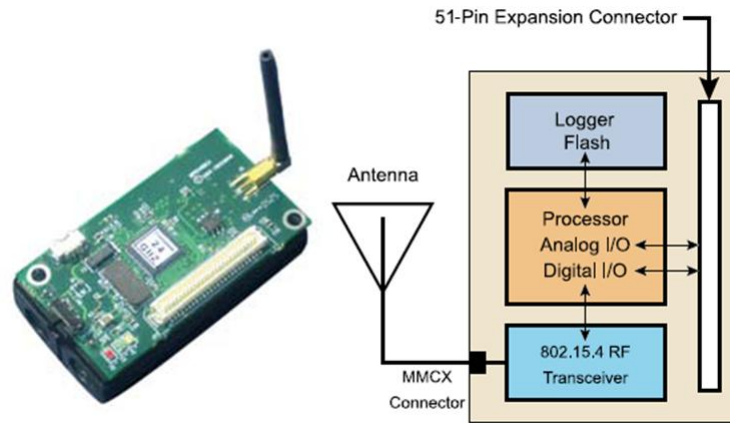


Figure 2.3: MICAz wireless sensor mote and Block diagram

MICAz is a zigbee based variant of MICA2 mote for high speed Sensor Networks. MICAz uses 2.4 to 2.48 GHz band for radio communication which is a globally compatible ISM band. Data rate of 250 kbps can be achieved with MICAz motes. These high data rate makes MICAz useful for gathering of acoustic, video, vibration and other high speed sensor data.

MICAz motes were used in first part of this research where the Radio Signal Strength Indicator (RSSI) was used to estimate the distance. The multipath fading and cross correlation were the major factors behind inaccurate distance estimation using radio signal strength.

## 2.2 Cricket Overview

Cricket project started in 2000 at MIT with a specific goal to create wireless sensor network based indoor location system. Cricket mote is built on MICA2 architecture. UltraSound transceiver and RS 232 serial interface are additionally implemented for specific localization application. Current upgraded version of cricket mote is version

2 which includes ultrasound signal with RF signal and RS 232 serial communication interface. In cricket based indoor location system, cricket motes can be assigned three different roles.

- **Beacon:** Cricket mote can be used as beacon mote whose geographical location is known. In most cases, beacons are attached to the fixed and stable object such as ceiling or wall. Beacons periodically broadcast their positions.
- **Listener:** Cricket mote can also be configured to work as listener mote which is moving in work space and whose space and position are unknown. Listener receives messages from the fixed beacons and computes its position.
- **Beacon and Listener:** In symmetric location based system, cricket mote can also be used as both beacon and listener. Figure 2.4 shows cricket layout and placement of major components. The following section include description of all important components.

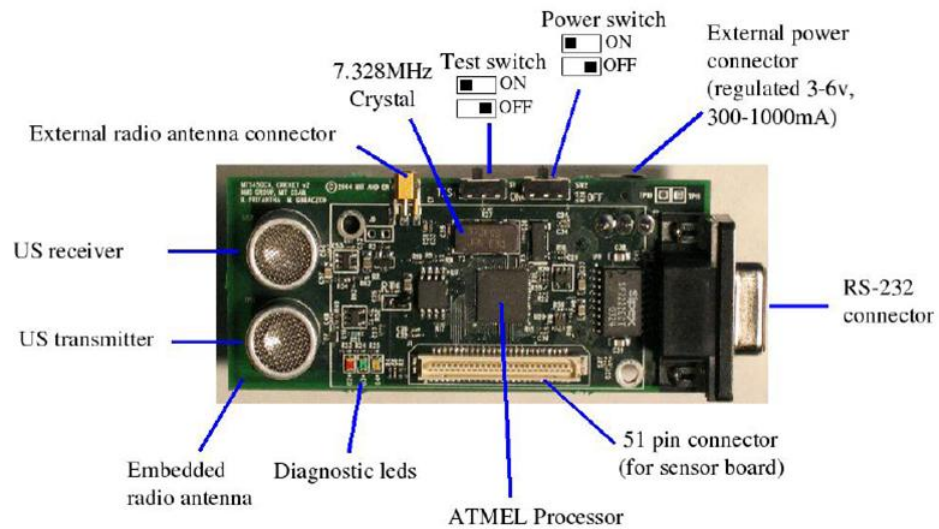


Figure 2.4: Cricket hardware components

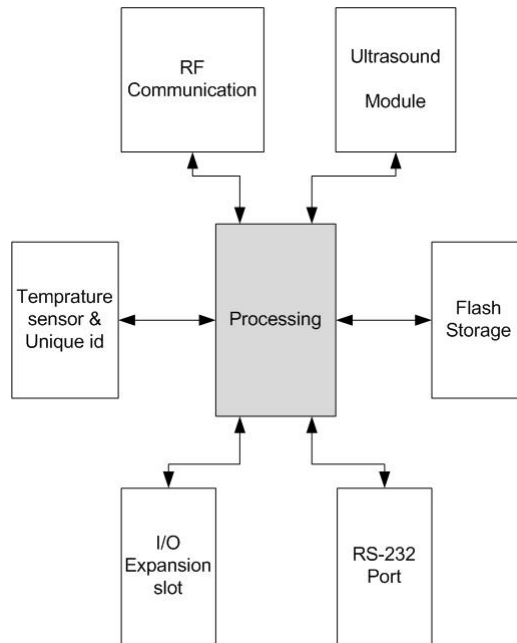


Figure 2.5: System architecture of The Cricket notes

### 2.3 Cricket System architecture

Figure 2.5 shows logical block diagram of cricket hardware implementation and simplifies complex hardware layout in the following logical modules.[11]

- **Processing Module:**

Cricket uses ATMEL Atmega 128L processor operating at 7.3728 Mhz in active and 32.768 kHz in sleep mode. The processor operates at 3 V and draws about 8 mA current in the active mode or  $8 \mu A$  in the sleep mode.

- **RF module:**

Cricket includes CC1000 RF radio configured to operate at 433 Mhz. Bandwidth of 19.2 kilobits/s can be configured for transmit and receive application.

- **Ultrasound Module:**

UltraSound module contains 40 kHz piezo-electric open-air ultrasonic transmitter which generates ultrasonic pulses of duration  $125 \mu s$ . It also includes open-air

type piezo-electric sensor whose output is connected to a two-stage amplifier with a programmable voltage gain between 70 dB and 78 dB.

- **Temperature sensor and Unique *ID*:**

A temperature sensor has been included with Cricket to change speed of Ultrasound signal with varying temperature. Cricket have An 8-byte hardware *ID*, which is similar to an Ethernet MAC address, uniquely identifies every Cricket node.

- **Flash Storage:**

128K Bytes flash storage is used to store cricket firmware.

- **I/O expansion Module:**

51 pin expansion connector is used to burn firmware on Cricket notes. It can also be used to connect different sensors modules with Cricket.

- **RS 232 Serial Interface:**

RS 232 serial interface is included with Cricket v2 to connect host computer with Cricket note.

## 2.4 Cricket Software architecture

Figure 2.6 shows the logical block diagram of the Cricket. The entire software architecture was divided in four different layers - Mote layer, Physical layer, Process layer and Application layer. Communication between listener and beacon is a part of Mote layer. Other three layers are at the computer end which uses data from Cricket notes to calculate distance and position.

TinyOs is used to create firmware of the Cricket listener and beacons. Physical layer application uses C language for serial communication. Process layer and Application layer applications are written in Java and are responsible for estimating the position using the user coded algorithms.

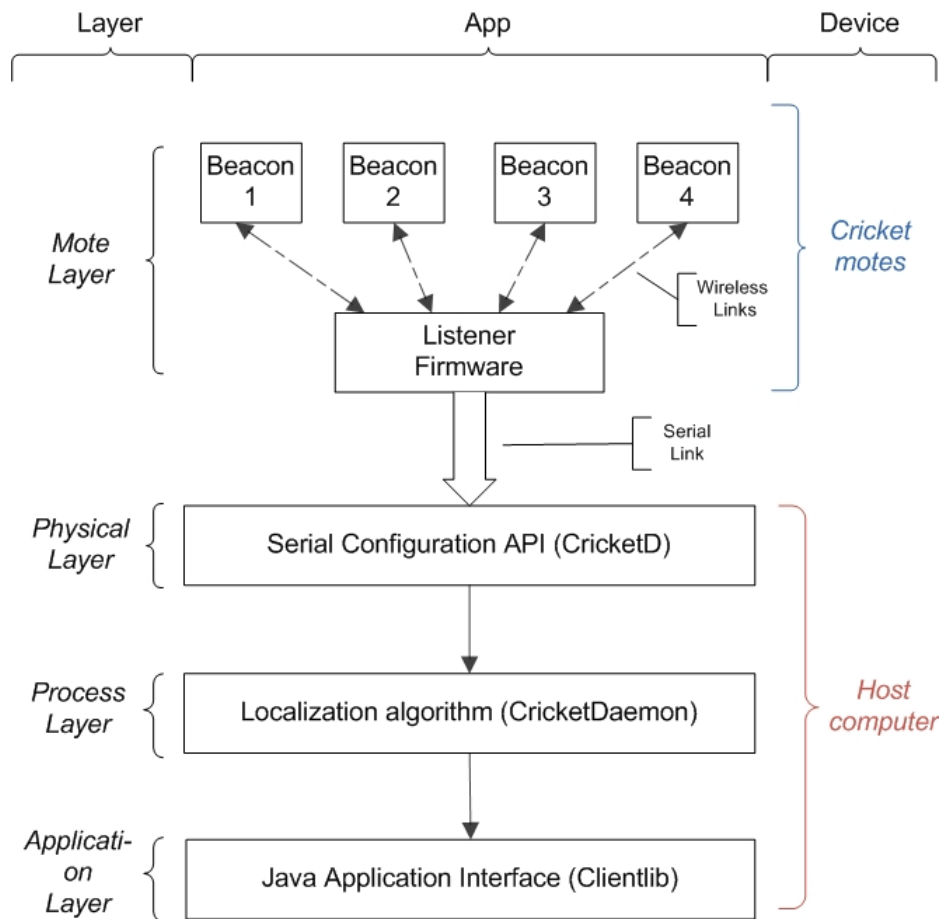


Figure 2.6: Software architecture of The Cricket motes

### 2.4.1 TinyOs and Cricket firmware

TinyOs was developed by UC Berkeley with co-operation of Intel research. TinyOs is a open source embedded operating system specially designed for wireless sensor networks. TinyOS is an event driven and component based operating system, eliminating multithreading and kernel to optimize memory limitations. This architecture is useful in achieving the goal of energy efficiency for wireless sensor networks.

Cricket listener and beacons have the same firmware but their role as a listener or a beacon is defined during configuration phase using RS-232 serial interface. The latest firmware 2.3.2 from MIT cricket website was used in this research. To burn firmware on Cricket motes, the base station is connected to a 51 pin expansion connector of the Cricket motes. RS-232 serial interface cannot be used to burn firmware.

Cricket firmware configured as a beacon is made up of two parts: one is responsible for scheduling RF and ultrasonic message transmission and second is a configuration API to communicate with RS 232 serial interface. Cricket firmware configured as a listener do have configuration API like beacon but it also has modules which are responsible for calculating distance and check collision detection. The listener uses a distance store module to communicate with beacons and update their distance table.

Cricket serial configuration API helps users to read and change values of cricket parameters using RS 232 serial interface. This API can be used to change parameters like mote state, space, ID, coordinates, ultrasound time of flight etc.

### 2.4.2 Software tools at Host end

Mote layer applications determine distance of each beacon to the listener mote. On the other hand, applications at computer end use raw data from listener mote for further processing and implementing algorithms to calculate accurate position. Three different applications are used for each computer end layers i.e. Physical layer, Process layer and Application layers.

- **CricketD :**

CricketD is a simple serial application written in C programming language. CricketD can be classified as Physical layer application because it interfaces cricket serial configuration API with computer serial port. CricketD binds serial port to the TCP port 2947 which can be used via telnet in network based application.

- **CricketDaemon :**

CricketDaemon is used to acquire raw beacon data from CricketD using TCP port 2947. CricketDaemon processes this raw data to calculate space and position of the listener. CricketDaemon is a JAVA API which requires CricketD already running to execute. Other application can access processed position and space information through TCP port 5001.

- **Clientlib Java at Application Layer :**

Cricket software package also includes Clientlib Java library for location-aware application development using Cricket notes. This library implements ServeBroker object which connects application to the CricketDaemon and implement callback interface. Different Java register can be created to get updates using ServerBroker object.

## 2.5 Chapter Summary

This chapter described the system and software architecture of different MICA series notes. In the next chapter, different distance and location estimation techniques for localization of the listener mote in experimental setup are described.

# 3

## Distance Estimation and Localization

This chapter discusses different techniques being used for distance estimation and localization. A brief introduction to Received Signal Strength Indicator(RSSI) based techniques, used previously, is included in section 3.1.1. The distance estimation technique based on TDoA is also explained in detail in section 3.1. Section 3.2 details multi-iteration technique used in position estimation of Cricket motes. This chapter also includes some experimental techniques for orientation calculation.

### 3.1 Distance Estimation Techniques

Distance or angle or both can be used as main parameters for location estimation. In a simple case, location of an unknown object from another known object can be found by using their distance and angle of their axis rotation. But in general, most of the location estimation algorithm uses either distance or angle as a parameter. To estimate location using lateration requires atleast three beacon motes. Thus, by elementary geometry position information can be classified in two approaches:

Lateration techniques uses distance between two objects for position calculation, as shown in Figure 3.1. In this thesis the distance based technique is used for calculation of the distance between motes. When angles between two nodes are used for



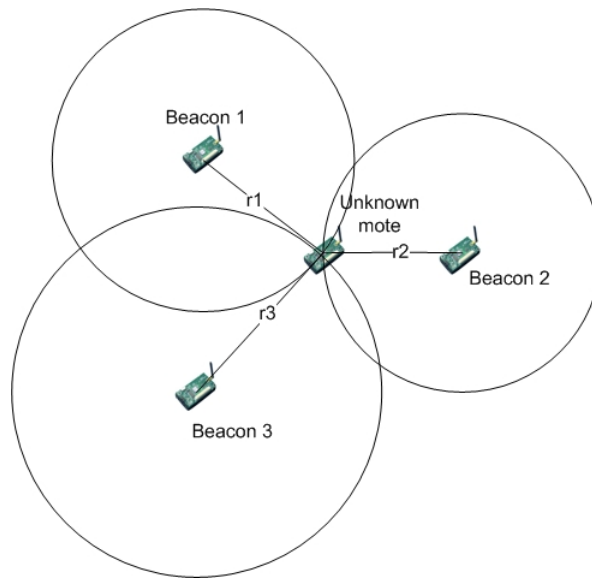


Figure 3.1: Simple Iteration Approach

position estimation, it is called angulation. Figure 3.2 is an example of angulation technique.

Received signal strength indicator (RSSI), Time of arrival (ToA) and Time difference of arrival (TDoA) are main techniques used in most of distance estimation based location estimation systems.

- Radio Signal Strength Indicator (RSSI) : RSSI based approaches use strength at receiver end, assuming transmission power and path loss are already known. RSSI based approaches are highly erroneous due to multipath fading and cross-correlation of signals. Though RSSI based approaches require less infrastructure, they are not suitable for accurate distance estimation.
- Time of Arrival (ToA) : The time of arrival approach uses time taken for a signal to arrive at receiver end using speed of signal and flight time distance. This approach requires highly synchronized beacon and listener, as speed of the signal is too high and a small error in time synchronization can produce unacceptable error in distance reading.

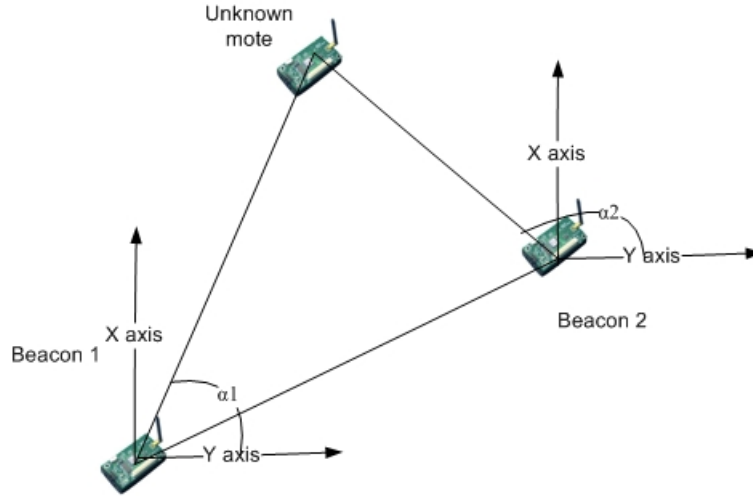


Figure 3.2: Simple angulation Approach

- Time Difference of Arrival (TDoA) : The TDoA approach uses two different signals with different speed for accurate distance estimation.

### 3.1.1 Experiments for Distance Estimation using MICAz motes

As a first step to distance estimation with wireless sensor network, an experiment was conducted with MICAz motes. As mentioned in chapter 2, MICAz uses Zigbee (IEEE 802.10.4) standard for radio communication. These experiments were carried out using two MICAz motes. One was used as transmitter (unknown) and other as listener (known). Moteview software from Crossbow Technologies was used to record RSSI measurements from transmitter MICAz mote to listener one. MICAz uses chipcon CC2420 IEEE 802.15.4 radio transceiver which operates in the 2.4 GHz ISM band. Thus radio transceiver includes a digital direct sequence spread spectrum (DSSS) modem which provides data rate of 250 kbps. Two different power levels were used in the experiment (-10 dBm and -25dBm) out of 8 supported power levels. [23]. This chipcon radio includes a built in 8 bit register for signal strength indicator which gives digital value of  $RSSI_{AL}$  [22]. so at receiver RF pin, we can gain

$$P = RSSI_{AL} + RSSI_{offset}[dBm] \quad (3.1)$$

where, P is power at receiver pin, and  $RSSI_{offset}$  is approximately -45 dBm which is front end gain [22]. Distance can be estimated using common signal propagation model:

$$RSSI(d) = P_T - P_L(d_0) - 10n \log_{10} \frac{d}{d_0} + X_\sigma \quad (3.2)$$

where  $RSSI(d)$  is the RSSI value at d distance node,  $P_T$  is transmitted power which is known,  $PL(d_0)$  is the reference path loss at distance  $d_0$ . n is the path loss exponent and  $X_\sigma$  is Gaussian random variable with zero mean and  $\sigma^2$  variance. The experiments using MICAz and this approach produced very erroneous results. The experiment were performed in the indoor and the outdoor environments. The result obtained had errors varying from 1.5 to 3 meters. In some cases the error was very high and was unacceptable for the application. The error was reduced with the increase in the number of notes. But they are mathematically quite complex and still inaccurate for the desired application.

### 3.1.2 Distance Estimation using Cricket notes

Finally, the decision was made to use Cricket for accurate distance estimation which deploys TDoA approach for distance estimation. Cricket uses a combined system of RF signal and Ultrasonic signal for distance estimation. Figure 3.3 illustrates distance estimation technique implemented by Cricket listener and beacons.

- It can be seen from the figure 3.3 that the beacon notes mounted on the ceiling first transmit a RF signal with message that contains beacon ID, space ID, coordinates of the beacon and measured ambient temperature. The beacon also transmit a narrow ultrasonic pulse at the beginning of the RF message rather than the RF signal itself. Ultrasonic pulse does not contain any data to reduce power consumption.

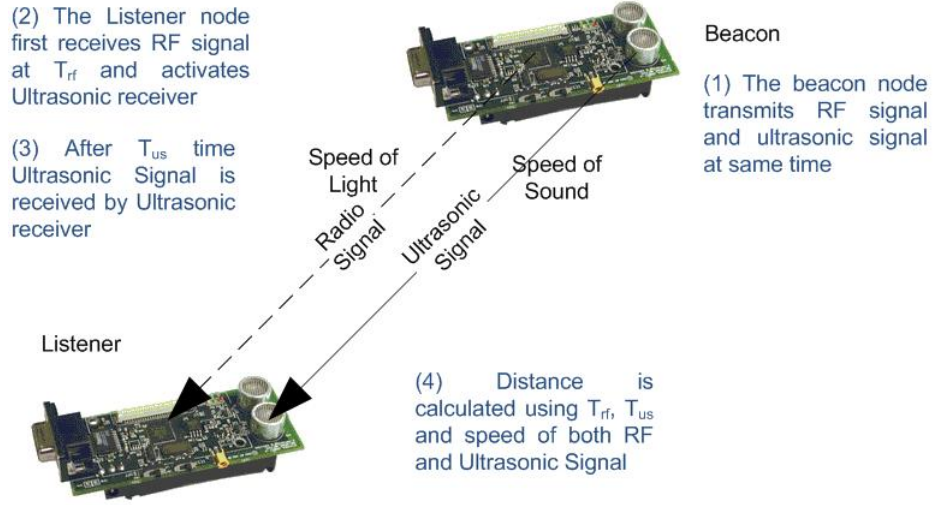


Figure 3.3: Time difference of arrival approach for distance estimation using cricket motes

- As a second step of the distance estimation process, Listener mote receives RF signal first because the velocity of the RF signal is much greater than the velocity of the ultrasound signal. After receiving the RF signal at time  $T_{rf}$  the listener mote activates the ultrasonic receiver and the timer.
- The listener mote receives ultrasonic pulse at time  $T_{us}$  and calculate the time difference of arrival  $\Delta T = T_{us} - T_{rf}$ .
- The distance  $d$  is then calculated using the following formula,

$$\Delta T = \frac{d}{V_{us}} - \frac{d}{V_{rf}} \quad (3.3)$$

$$d = \frac{\Delta T (V_{us} \cdot V_{rf})}{(V_{rf} - V_{us})} \quad (3.4)$$

- The velocity of the RF signal is approximately  $3 \times 10^8$  m/s while the velocity of the ultrasonic signal depends upon the temperature and humidity, which is 344 m/s at normal room temperature and humidity. Since  $V_{rf}$  is much larger than  $V_{us}$  at all working temperature equation 3.4 can be written as

$$d = \frac{\Delta T (V_{us} V_{rf})}{V_{rf}} = \Delta T \cdot V_{us} \quad (3.5)$$

- Equation (3.5) is used as a standard equation for distance estimation with system containing cricket notes. In some cases, for better results, we can alter the speed of ultrasonic signal with temperature results obtained from beacon notes.

## 3.2 Location Estimation Techniques

After determining the distance of each beacon with respect to listener mote, the next step is to implement the position and orientation estimation algorithms to calculate accurate coordinates of the Listener mote.

### 3.2.1 Experimental Setup for location estimation

Figure 3.4 illustrates the experimental setup to estimate the location of the listener mote. Beacon one to four are fixed to ceiling with their coordinates already measured and burned to their firmware. Setup also include a stage of 180 cm x 120 cm for movement of the listener. The listener can be moved on the stage manually or mounted on top a mobile robot. A computer, connected to the listener via serial port, is used to host software for serial communication and run Graphical User Interface (GUI) for location estimation.

### 3.2.2 Position Estimation

This section explains multiteration technique used in cricket notes for position estimation. The Extended Kalman Filter based approach can be used to overcome minor errors generated during implementation of the multiteration algorithm.

Cricket notes are capable of estimating distance with an average of 2 centimeter accuracy and a range of 10 meters [11]. Since the speed of the signals vary with temperature, a built in temperature sensor that calculates the current temperature can be used to measure the speed of the ultrasound signal accurately. The estimation of the position, for beacons and listeners that are in line of sight (LOS), is carried out by combining three different steps: least squares minimization (LSM), Extended

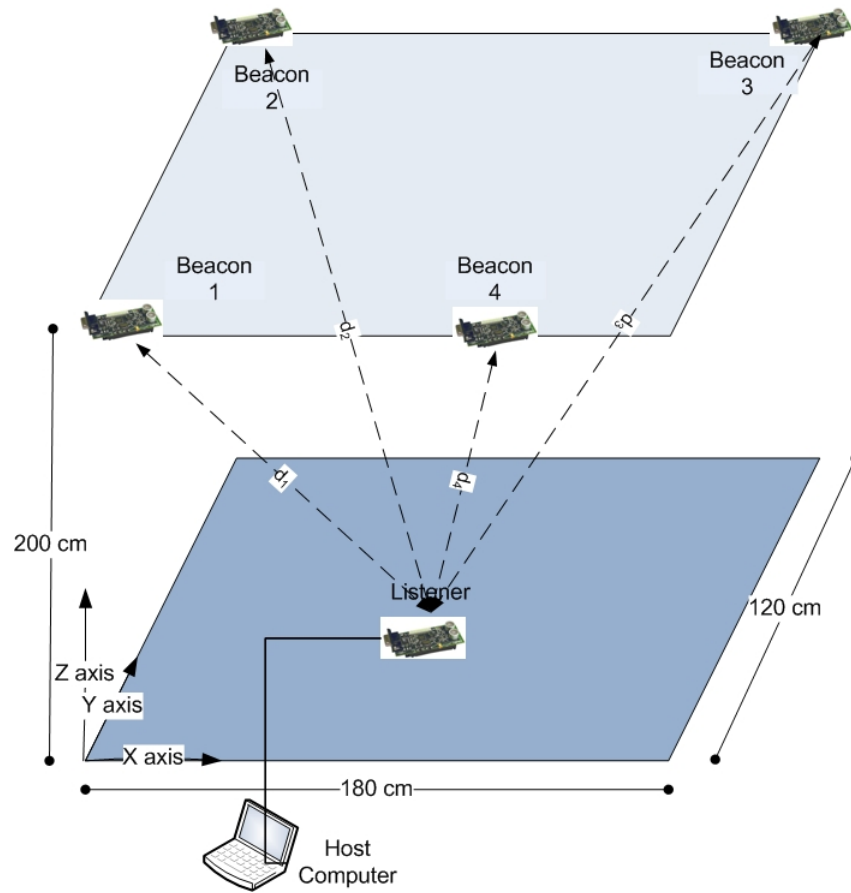


Figure 3.4: Experimental setup for the position estimation

Kalman Filter ( EKF ) and outlier rejection. The least squares minimization ( LSM ) technique estimate position by minimizing the sum of the squares of the error with respect to each distance sample. For a system with three beacon notes, i.e.  $i=3$ , in the  $z = 0$  plane, equation (3.6) is used to find the  $x$ ,  $y$ , and  $z$ -position of the listener using triangulation [11]

$$(x - x_i)^2 + (y - y_i)^2 + z^2 = v^2 t_i^2, \quad i \geq 3 \quad (3.6)$$

where  $v$  is the speed of sound,  $t_i$  is the time taken from the respected beacon to listener, and  $(x_i, y_i)$  is the known position of beacon  $i$ . After eliminating  $z^2$  by subtracting the three equations (equation (3.5) for different  $i$  values) from each other, the resulting equations can be solved for the unknown position  $(x, y, z)$  of the object with respect to a beacon.

To understand the equation (3.6) consider a system with three beacon notes at positions B1; (0,0,0), B2;(10,0,0) and B3;(10,10,0). The coordinates of the listener mote is unknown i.e.  $(x,y,z)$  and distance of the listener mote obtained from the beacon notes B1,B2 and B3 is 10.19, 12.80 and 12, respectively. Equation (3.6) for beacons B1,B2 and B3 will be,

$$(x - 0)^2 + (y - 0)^2 + z^2 = x^2 + y^2 + z^2 = (10.19)^2 \quad (3.7)$$

$$(x - 10)^2 + (y - 0)^2 + z^2 = x^2 + y^2 + z^2 - 20x + 100 = (12.80)^2 \quad (3.8)$$

$$(x - 10)^2 + (y - 10)^2 + z^2 = x^2 + y^2 + z^2 - 20x - 20y + 200 = (12)^2 \quad (3.9)$$

Subtracting equation (3.7) from (3.8),

$$-20x + 100 = 60$$

$$\therefore \text{value of } x = 2$$

Similarly subtracting equation (3.8) from (3.9),

$$-20y + 100 = -19.84$$

$$\therefore \text{value of } y = 5.992 \approx 6$$

Substituting values of  $x$  and  $y$  in equation (3.7) will give,

$$(2)^2 + (6)^2 + z^2 = (10.19)^2 = 103.83$$

$$\therefore z^2 = 63.836$$

$$\therefore z \approx +8 / -8$$

The coordinates of the listener mote derived from the above method are  $(2,6,\pm 8)$  and sign of the  $z$  coordinate can be determined by the positioning of the beacon motes.

For a system with more than 3 beacons motes, the positions of the listener can be found more accurately using the least square error since there are more equations than the unknowns [12].

Cricket software developed for the cricket motes also implements Extended Kalman Filter based approach. This approach is used when estimated distance has a large amount of error compared to measured distance.

### 3.2.3 Orientation Estimation

Since the orientation data is not used in this thesis, this section only include overview of a simple orientation technique that can be implemented by minor modifications in commercial Cricket motes.

To find the orientation of the object, it is assumed that the Cricket mote is equipped with two ultrasound receiver. Using the techniques described in section 3.2, two different coordinates for these ultrasound receiver can be obtained i.e.  $(x_1, y_1, z_1)$  and  $(x_2, y_2, z_2)$ .

The coordinates estimated by two ultrasound receiver create one line segment. Figure 3.5 shows the two ultrasound receiver with the line segment. The orientation of the segment can be found as [3],

$$\alpha = \cos^{-1}(x_1 - x_2)/L \quad (3.10)$$

$$\beta = \cos^{-1}(y_1 - y_2)/L \quad (3.11)$$

$$\gamma = \cos^{-1}(z_1 - z_2)/L \quad (3.12)$$



where  $\alpha$ ,  $\beta$ , and  $\gamma$  are the angles of rotation about the X, Y and Z-axes. L is the length of the line segment.

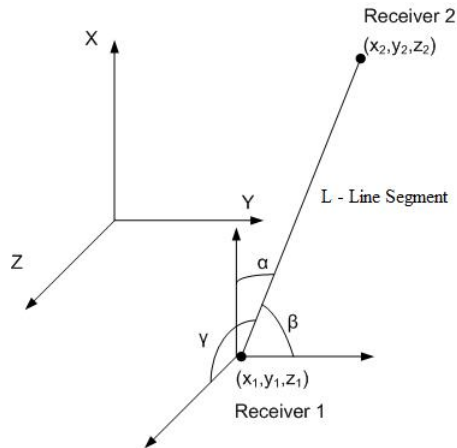


Figure 3.5: A simple orientation estimation technique

### 3.3 Chapter summary

This chapter discusses different distance estimation schemes and TDoA scheme used for Cricket notes. This chapter also explained location estimation used in development of this thesis.

The next chapter will discuss Pan/Tilt gimbal camera system and transformation equations needed for surveillance.

# 4

## Surveillance and Transformation

As described in previous chapters, this thesis combines wireless sensor network for localization and Pan/Tilt gimbal camera systems for surveillance. Chapters 2 and 3 described the cricket wireless nodes for distance and position estimation technique. This chapter discusses the Pan/Tilt gimbal camera system and the transformations used to locate the listener node with respect to the camera. This chapter also describes transformation mathematics to calculate Pan and Tilt rotation angles.

### 4.1 Surveillance Camera assembly

Figure 4.1 illustrates the Pan-Tilt gimbal mounted on ceiling with the surveillance camera system. The surveillance system is fabricated using two main portions.

#### 4.1.1 Pan-Tilt Gimbal module

A custom kit provided by Lynxmotion Inc was used to create the Pan-tilt Gimbal.

- **Gimbal:**

The Gimbal includes two servo motors and corresponding mounting parts, which is responsible for pan and tilt movement of the entire camera system. Figure 4.1 describes pan and tilt axes which are responsible for horizontal and vertical movements of the camera system respectively.

- **Phidget Advanced Servo Controller:**

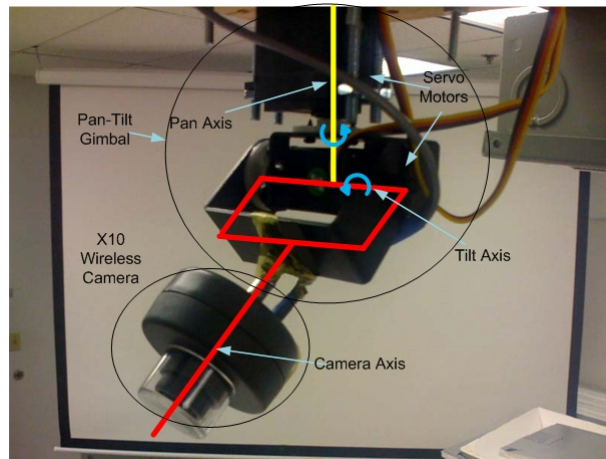


Figure 4.1: Pan-Tilt Gimbal and X10 camera assembly

Both servo motors are operated by servo motor controller manufactured by Phidget Inc. Phidget Advanced servo controller is capable of handling four servo motors at same time with help of host computer connected via Universal serial Bus (USB) port.

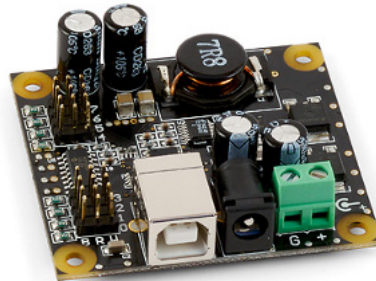


Figure 4.2: Phidget Advanced servo Controller [25].

#### 4.1.2 X10 Wireless camera system

The X10 system consists of X11A wireless camera and VR42A AV receiver to survey the location estimated by the cricket system. Figure 4.1 shows the mount location of the wireless camera on the gimbal.

- **X11A Wireless Camera:**

The X11A camera manufactured by X10.com Inc, is an industry standard wireless security camera. It is a part of security surveillance system which also includes a receiver and USB AV converter. X11A has a 2.4 GHz radio link with 4 switchable RF channels. The purpose of using the X11A camera is to simulate wireless remote monitoring of the localization and surveillance results. Though the area covered in video is wider than the actual listener mote, X11A camera successfully demonstrated the approximate listener position.

- **VR42A Audio-Video Receiver:**

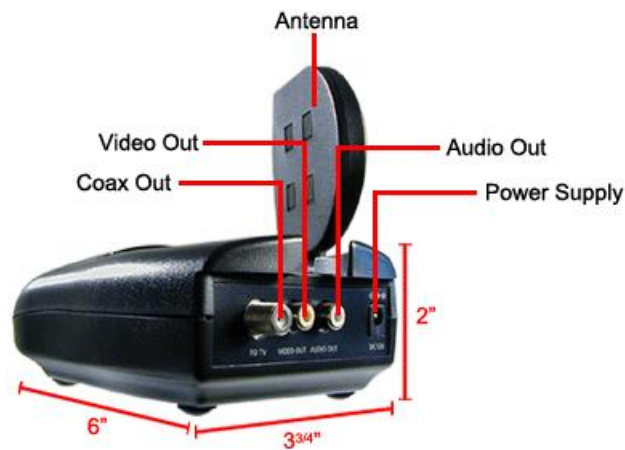


Figure 4.3: VR42A Audio Video receiver for X10 camera System[24].

Figure 4.3 shows a VR42A Audio-Video receiver used with X11A camera. VR42A can be used within 100 feet radius of the X11A location due to the range of the camera. Output of the receiver can be watched on a television using AV output or on a computer by extending AV output via USB video converter.

- **Laser mount:**

The camera used in this thesis does not have the zoom capability and, therefore, it is difficult to determine if the camera is looking accurately at the proper location. A commercial laser was mounted on top of the camera to point to the accurate

intersection of the camera axis and the listener plane.

## 4.2 Co-ordinate Systems and Rotation

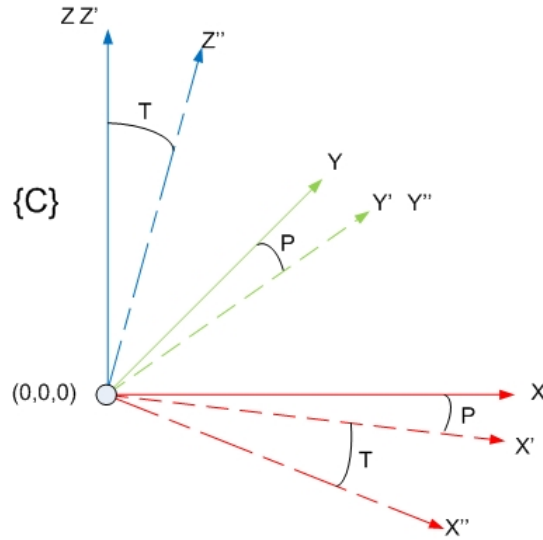


Figure 4.4: Pan and Tilt rotation of the Co-ordinate system

After the localization is complete, it is desired to direct the camera toward the listener mote for surveillance. To focus the camera on the object, the camera assembly needs to be rotated along the horizontal and the vertical directions which are better known as pan and tilt rotation of the gimbal, respectively.

The X-axis in Figure 4.4 is the camera axis passing through the center of the camera lens. For the camera to accurately focus on the listener mote, the camera axis, i.e. X-axis, should align with the X-axis of the listener mote. To achieve this, Z and Y-axis need to be rotated in such a way that the camera X-axis align with the X-axis of the listener mote.

To align the X-axis, the rotation of the Z-axis in XY plan is called the Pan rotation (P). Similarly rotation of the Y-axis in XZ plan is called the Tilt rotation (T). After the pan and tilt rotation of the Z and Y axes respectively, camera X-axis will be aligned with the X-axis of the listener mote.

### 4.3 Transformation Mathematics

Section 4.2 described the concept of the pan and the tilt rotation angles. This section illustrates the mathematics associated with the calculation of pan and tilt rotation angle using two known locations of the beacon and the camera; and the estimated location of the listener mote.

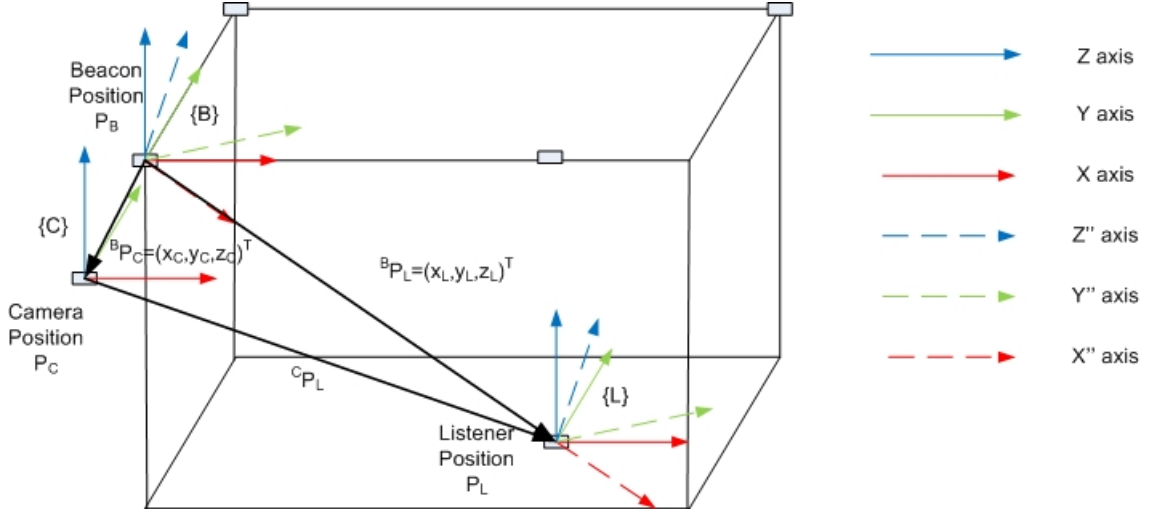


Figure 4.5: Co-ordinate systems and rotations before Origin transformation

Figure 4.5 illustrates preliminary co-ordinate system and location before any transformation. The origin is located at a beacon position  $P_B$  while the listener position  $P_L$  and the camera position  $P_C$  are shown in accordance to the beacon co-ordinate system. The position matrices can be written as,

$${}^B P_L = (x_L, y_L, z_L)^T$$

$${}^B P_C = (x_C, y_C, z_C)^T$$

The distance between the listener mote and the beacon is given by,  $d = \sqrt{x_L^2 + y_L^2 + z_L^2}$ , is used to calculate the pan and the tilt angles. Though it is simple to calculate the pan and the tilt angle using the geometry for a single case, a generalized transformation matrix is required to deal with rapidly changing co-ordinates of the camera and the listener.

The method to calculate the generalized pan and tilt equation requires transfor-

mation of the origin from the beacon to the camera. The orientation of the camera frame C and the beacon fram B are same. New co-ordinates of the listener motes i.e.  ${}^C P_L = (x_{LN}, y_{LN}, z_{LN})^T$  after origin transformation can be calculated by,

$${}^C P_L = {}^C P_B + {}^C R_B \cdot {}^B P_L$$

Where  ${}^C R_B = I$ ,

$$\therefore {}^C P_L = -{}^B P_C + {}^B P_L = \begin{bmatrix} x_L - x_C \\ y_L - y_C \\ z_L - z_C \end{bmatrix}$$

In this conditions, the distance from the camera to the listener will be,

$$d_N = \sqrt{x_{LN}^2 + y_{LN}^2 + z_{LN}^2}$$

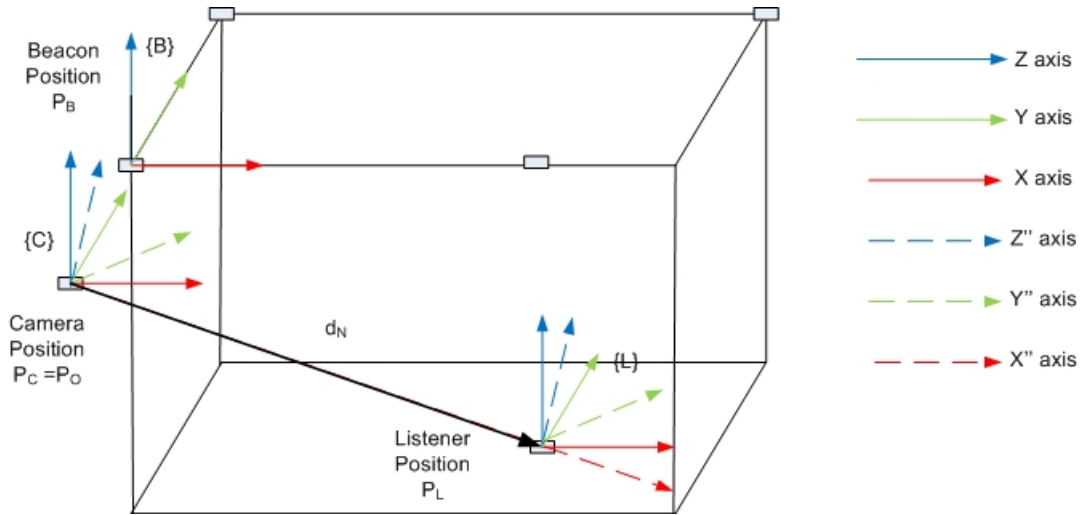


Figure 4.6: Co-ordinate systems and rotations after Origin transformation from the beacon to the camera

Figure 4.6 illustrates that, rotated  $X''$  axis now passes by the X-axis of the listener. To achieve this position, the camera co-ordinate system needs to be rotated by pan,  $\phi$ , and tilt,  $\theta$ , angles resulting in a new co-ordinate the aligns the camera co-ordinate system with the listener mote.

$$\begin{aligned}
{}^L P_L &= {}^L R_C \cdot {}^C P_L \\
\text{where } {}^L R_C &= R(y, \theta) \cdot R(z, \phi) = \begin{bmatrix} C_\theta & 0 & S_\theta \\ 0 & 1 & 0 \\ -S_\theta & 0 & C_\theta \end{bmatrix} \begin{bmatrix} C_\phi & -S_\phi & 0 \\ S_\phi & C_\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \\
\therefore {}^L R_C &= \begin{bmatrix} C_\theta C_\phi & -C_\theta S_\phi & S_\theta \\ S_\phi & C_\phi & 0 \\ -S_\theta C_\phi & S_\theta S_\phi & C_\theta \end{bmatrix} \tag{4.1}
\end{aligned}$$

Using the value of  ${}^L R_C$  from equation (4.1),  ${}^L P_L$  can be rewritten as,

$${}^L P_L = \begin{bmatrix} C_\theta C_\phi & -C_\theta S_\phi & S_\theta \\ S_\phi & C_\phi & 0 \\ -S_\theta C_\phi & S_\theta S_\phi & C_\theta \end{bmatrix} \begin{bmatrix} x_{LN} \\ y_{LN} \\ z_{LN} \end{bmatrix} \tag{4.2}$$

As the result of these rotations the distance between the camera and the listener,  $d_N$ , will become x co-ordinate and other the co-ordinates will be zero. The new position matrix of the listener mote in accordance to the rotated co-ordinate system can be written as,

$${}^L P_L = (d_N, 0, 0)^T \tag{4.3}$$

By comparing equation (4.2) and (4.3),

$${}^L P_L = \begin{bmatrix} d_N \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} C_\theta C_\phi & -C_\theta S_\phi & S_\theta \\ S_\phi & C_\phi & 0 \\ -S_\theta C_\phi & S_\theta S_\phi & C_\theta \end{bmatrix} \begin{bmatrix} x_{LN} \\ y_{LN} \\ z_{LN} \end{bmatrix} \tag{4.4}$$

Equation (4.4) is a generalized matrix form to calculate pan and tilt angles in accordance to the any given camera position. Individual values of the pan angle  $\phi$  and the tilt angle  $\theta$  can be calculated by comparing both side of matrices. Following are the three equation obtained from the matrices,

$$d_N = C_\theta C_\phi(x_{LN}) - C_\theta S_\phi(y_{LN}) + S_\theta(z_{LN}); \tag{4.5}$$



$$S_\phi(x_{LN}) + C_\phi(y_{LN}) = 0; \quad (4.6)$$

and

$$-S_\theta C_\phi(x_{LN}) + S_\theta S_\phi(y_{LN}) + C_\theta(z_{LN}) = 0; \quad (4.7)$$

From equation (4.6) ,

$$\frac{S_\phi}{C_\phi} = \frac{-y_{LN}}{x_{LN}}$$

Therefore the pan angle  $\phi$  is given by,

$$\phi = \text{atan2}(-y_{LN}, x_{LN}) \quad (4.8)$$

Once the pan angle is known equation (4.5) and (4.7) to calculate the tilt angle  $\theta$ ,

$$C_\theta(C_\phi x_{LN} - S_\phi y_{LN}) + S_\theta(z_{LN}) = d_{LN} \quad (4.9)$$

$$C_\theta(z_{LN}) + S_\theta(-C_\phi x_{LN} + S_\phi y_{LN}) = 0 \quad (4.10)$$

Since the pan angle is known, the value of  $C_\phi x_{LN} - S_\phi y_{LN}$  is known and let,

$$C_\phi x_{LN} - S_\phi y_{LN} = A \quad (4.11)$$

Substituting equation (4.11) into equations (4.9) and (4.10) ,

$$C_\theta A + S_\theta z_{LN} = d_N \quad (4.12)$$

$$C_\theta z_{LN} - A S_\theta = 0 \quad (4.13)$$

Solving equation (4.12) and (4.13) using cramer's rule,

$$C_\theta = \frac{\begin{vmatrix} d_N & z_{LN} \\ 0 & -A \end{vmatrix}}{\Delta} \quad (4.14)$$

and,

$$S_\theta = \frac{\begin{vmatrix} A & d_N \\ z_{LN} & 0 \end{vmatrix}}{\Delta} \quad (4.15)$$

Therefore tilt angle,  $\theta$ , can be calculate from equation (4.14) and (4.15) ,

$$\theta = \text{atan2}(-d_N z_{LN}, -Ad_N)$$

$$\therefore \theta = \text{atan2}(z_{LN}, A) \tag{4.16}$$

#### 4.4 Summary

In this chapter the Pan/Tilt gimbal and X10 wireless camera system needed for surveillance are described. The equations needed to calculate the pan and the tilt angles are also described in this chapter.

# 5

## Results and Possible Applications

This section summarizes the results obtained by the Master-Slave system of wireless sensor network and Pan/Tilt Gimbal Camera system to locate and track listener mote on an experimental setup. This chapter further describes applications space associated with the research.

### 5.1 Results

The experiment was divided into three major parts of estimating the distance, locating the object and finally surveying the object using camera.

- Distance estimation experiment was held indoor using one beacon mote and one listener mote. During this experiment, the beacon mote and the listener mote were aligned facing their ultrasonic receivers for the range of 0 to 200 cm. The maximum error observed was 0.529 cm at 200 cm with average error of 0.14 cm and average standard deviation of 0.00944 cm. Figure 5.1 shows the error in distance estimation with respect to the actual distance.
- The location estimation experiments were conducted using four beacon motes and a listener motes as described in Section 3.2. The experiments were carried out on (180 cm X 120 cm) workspace. Table 5.1 shows the experimental result obtained for the location estimation. Maximum error measured was (2.14 cm, 1.82 cm) at position (180 cm, 120 cm) with the average error of (0.999 cm, 0.645 cm).

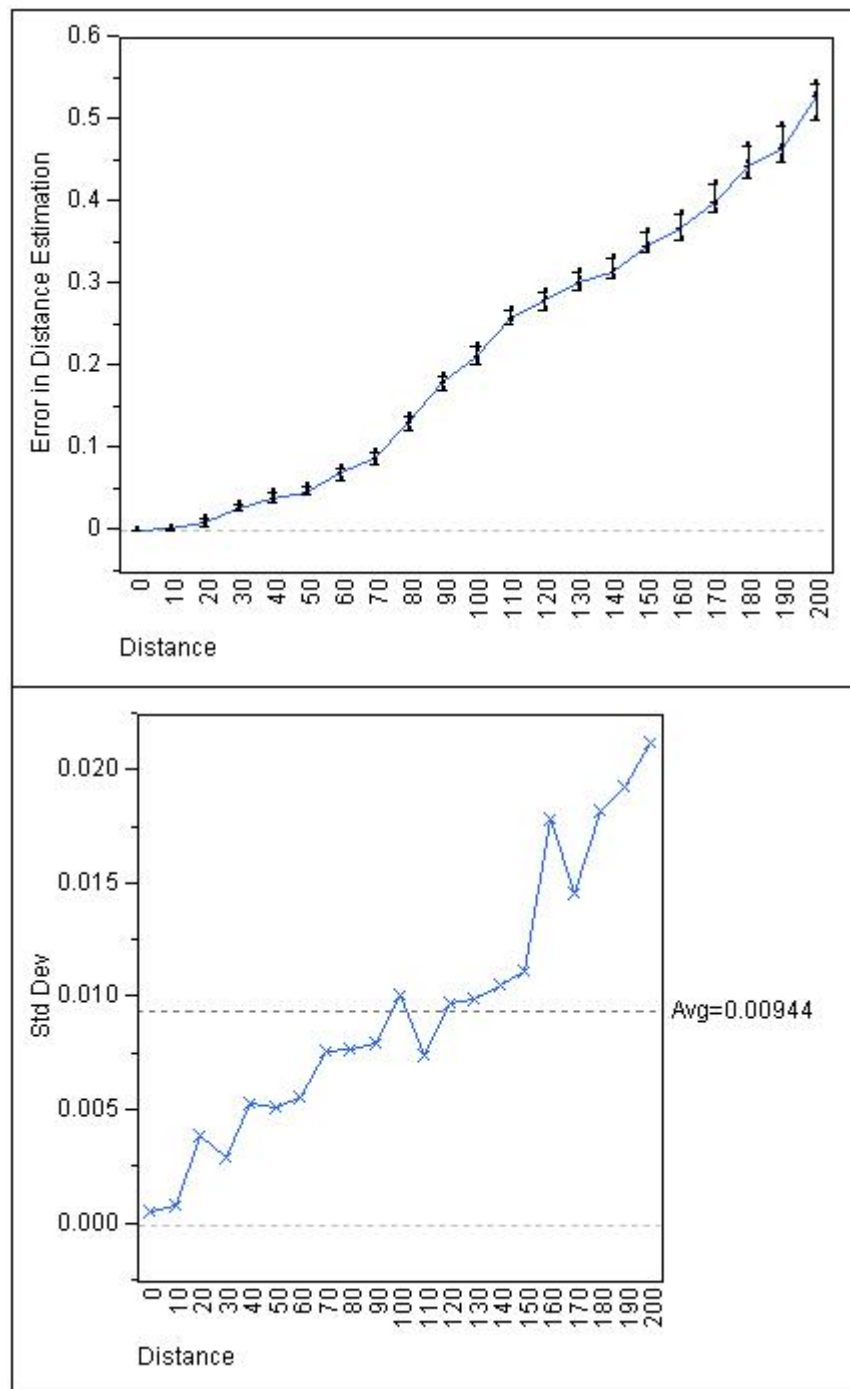


Figure 5.1: Actual distance vs Error in distance estimation

Actual Position		Error in Position Estimation	
X cm	Y cm	Error in X cm	Error in Y cm
0	0	0	0
45	0	0.55	-0.23
90	0	1.05	-0.43
135	0	1.72	-0.68
180	0	2.06	-0.9
0	30	-0.14	0.53
0	60	-0.24	0.92
0	90	-0.33	1.35
0	120	-0.5	1.78
45	30	0.53	0.46
45	90	0.54	1.46
90	60	1.07	0.89
135	30	1.63	0.51
135	90	1.69	1.78
180	30	2.05	0.49
180	60	2.1	0.87
180	90	2.07	1.32
180	120	2.14	1.82

Table 5.1: Comparison of Actual position and the error between the actual position and the position obtained from the Cricket system.

- Similar experiments were carried out using the same mote setup but added camera gimbal with mounted laser pointer to point the location when the camera is focusing on. The error pattern achieved during these experiments were marginally different from the previously obtained results in the location estimation experiments. These experiments showed increasing error on the edges of the experimental plane. These errors were the result of the error introduced by the tilt angle and limitation of the servo motor step size. Because of the restriction in the positioning of the camera, the entire experimental space was covered by the tilt angle range of 0-30 *degrees*. Table 5.2 shows experimental results obtained

by implementing transformation algorithm for the gimbal system and the error between actual position and the position pointed by the laser. Maximum error obtained during this experiment is (5.19 cm,4.94 cm) with the average error of (2.57 cm,1.92 cm).

Actual Position		Error in Position Estimation	
X cm	Y cm	Error in X cm	Error in Y cm
0	0	0.12	-0.24
45	0	0.54	-0.21
90	0	2.63	-0.40
135	0	4.85	-0.72
180	0	5.21	-0.98
0	30	-0.12	0.53
0	60	-0.24	0.92
0	90	-0.33	3.65
0	120	-0.49	4.91
45	30	0.62	0.87
45	90	0.52	1.46
90	60	1.07	0.89
135	30	2.63	1.51
135	90	3.78	3.69
180	30	4.97	0.56
180	60	5.07	0.98
180	90	5.16	3.52
180	120	5.19	4.94

Table 5.2: Actual position and the error between position and the position pointed by laser system.

The results obtained in this project are more accurate as compared to the results from the indoor localization systems described in chapter 1. The results also shows that the transformation equation derived for the camera gimbal system are correct.

## 5.2 Possible Application

This system can be used in the following application space with minor modification.

### 5.2.1 Army

- System proposed in this thesis can be used for surveillance and tracking of micro Unmanned Ground Vehicle(UGV) inside building.
- Pre established sensor network can also help autonomous UGV for area surveillance.
- Allied soldiers with a listener mote can be easily differentiated from enemy soldiers in urban war zone.

The terrorist attack in Mumbai, India is best example of the application space of this system. A group of terrorist taking shelter in a huge hotel building or a public place can be tracked easily with an established sensor network inside the buildings.

### 5.2.2 Home Appliances

- A simple application of this system can be autonomous lawnmower. A fixed sensor network can be used to localize and track lawnmower.
- This system can also be used to track infant child in a house and track its movements.

### 5.2.3 Health Care

- As mentioned earlier in the scenario of a wheel chaired person, this approach can be directly implemented in buildings with a significant amount of wheelchair traffic. Pre established camera network can be attached to the localization system to monitor a disable person in emergency condition.
- Patient monitoring system can also be implemented using this system.

#### 5.2.4 Environment Monitoring

- A modified version of the sensor network with extended battery life and environmental friendly motes can be used to monitor endangered species. The behavior of such species can also be monitored using the sensor network and the camera. Though this application may require large number of sensor motes, it can be a useful approach for monitoring a small area.
- Approaches had been proposed and implemented to detect wildfire using pre-established sensor networks. In these approaches, sensor motes with temperature sensor are used to detect surrounding temperature and environmental condition. Adding accurate localization and PTZ camera may avoid false alarms by surveillance of the suspicious wildfire area with camera system. In some cases it can also detect the source of wildfire and help to prevent future wildfire.



# 6

## Summary and Conclusion

This chapter summarizes the localization and surveillance system developed in this thesis using Cricket motes and Pan/Tilt camera. The chapter also discusses potential future expansions for broadening the application space of the developed system.

### 6.1 Summary and Conclusion

The Cricket wireless system pose an advanced solution for accurate indoor distance estimation and position. The Cricket system is easy to deploy, is cost effective and gives accurate results compare to conventional localization system such as GPS. In this thesis, a system level approach for indoor surveillance of objects using wireless sensor network and Pan/Tilt gimbal is proposed. The difference of time of arrival (TDoA) approaches is used to estimate the distance of the object using cricket motes. The maximum error of 0.5 cm at 200 cm with average error of 0.14 cm was obtained during distance estimation experiments. The position estimation experiments were carried out by implementing multilateration algorithm. The Maximum error obtained in position estimation experiment is (5.19 cm,4.94 cm) with the average error of (2.57 cm,1.92 cm). The position of the object is then transformed into the camera coordinate system using the homogeneous transformation matrices. This position is then used to calculate the pan and tilt angle for the camera to track the object using the Pan/Tilt Gimbal system. A program developed in JAVA environment is used to interface the gimbal and the Cricket system with the host computer. The accuracy

of the Pan/Tilt gimbal system was tested using a laser pointer mounted on top of the camera and was shown that the system tracked the object with negligible error.

## 6.2 Challenges and Future Work

- This Wireless Sensor Networks used in thesis are not implemented with any sensor attachment besides the already embedded RF and Ultrasonic communication modules. Application space can be expanded by attaching temperature and pressure sensor extensions. This system can be implemented for environmental monitoring.
- The system developed is only able to localize one listener object. Adding functionality of locating more than one listener mote can be implemented for applications that require co-ordination between objects. An example of such system is the coordination between a UAV(Unmanned Ariel Vehicle) and a UGV(Unmanned Ground Vehicle) in an indoor hostile area.
- The software tools, developed in this thesis, the identity of the listener and the beacon motes are predefined. A technique to define the role of the mote with dynamic role assignment will help to create dynamic sensor network. Though the coverage area of this dynamic sensor network is limited with the number of mobile motes, the whole coverage area moves with the movement of the mobile motes according the application.
- The camera/gimble system used in this thesis has two degree of freedom in Pan and Tilt directions. A camera with the zoom capability can improve surveillance result by focusing the camera on the listener mote by varying the focal length.

# References

P. Bahl and V. Padmanabhan, *RADAR: An In-Building RF-based User Location and Tracking System*, In Proc. IEEE INFOCOM, Tel-Aviv, Israel, Mar. 2000.

Adam Smith, Hari Balakrishnan, Michel Goraczko, Nissanka Priyantha, *Tracking Moving Devices with the Cricket Location System*, Proc. 2nd USENIX/ACM MOBISYS Conf., Boston, MA, June 2004.

Nissanka B. Priyantha, Anit Chakraborty, Hari Balakrishnan, *The Cricket Location-Support system*, Proc. 6th ACM MOBICOM, Boston, MA, August 2000.

Nissanka B. Priyantha, Allen Miu, Hari Balakrishnan, and Seth Teller, *The Cricket Compass for Context-Aware Mobile Applications*, Proc. 7th ACM MOBICOM, Rome, Italy, July 2001.

R. Want, A. Hopper, V. Falcao, and J. Gibbons., *The Active Badge Location System*, ACM Transactions on Information Systems, 10(1):91102, January 1992.

Holger Karl and Andreas Willig, *Protocols And Architectures For Wireless Sensor Networks*, John Wiley and Sons Ltd., ISBN: 0-470-09510-5.

Guoqiang Mao, Baris Fidan and Brian D.O. Anderson, *Wireless sensor network localization techniques*, A Computer Networks: The International Journal of Computer and Telecommunications Networking, Volume 51 , Issue 10 (July 2007), pp. 2529-2553, ISSN:1389-1286.

David Malan, Thaddeus Fulford-Jones, Matt Welsh, and Steve Moulton, *CodeBlue:*

*An Ad Hoc Sensor Network Infrastructure for Emergency Medical Care*, International Workshop on Wearable and Implantable Body Sensor Networks, April 2004.

G. Werner-Allen, K. Lorincz, M. Ruiz, O. Marcillo, J. Johnson, J. Lees, and Matt Welsh, *Deploying a wireless sensor network on an active volcano*, M. Internet Computing, IEEE Volume 10, Issue 2, March-April 2006, pp. 18-25.

I. Everts, N. Sebe, and G. Jones, *Cooperative Object Tracking with Multiple PTZ Cameras*, 14th International Conference on Image Analysis and Processing, 2007. ICIAP 2007.

Nissanka Bodhi Priyantha, *The Cricket Indoor Location System*, Ph.D. Thesis, Massachusetts Institute of Technology, June 2005.

A. K. L. Miu, *Design and Implementation of an Indoor Mobile Navigation System.*, M.S. Thesis, Massachusetts Institute of Technology, May 2002.

I. Getting, *The Global Positioning System*, IEEE Spectrum, 30(12):3647, December 1993.

H. A. El-Natour, C. Macabiau, M. L. Boucheret, and A. C. Escher, *Impact of Multipath and Cross-Correlation on GPS Acquisition in Indoor Environments*, In Institute of Navigation, National Technical Meeting, San Diego, CA, January 2005.

R. Want, Andy Hopper, Veronica Falco and Jonathan Gibbons, *The Active Badge Location System*, ACM Trans. Info. Sys., Jan. 1992.

A. Harter, A. Hopper, P. Steggles, A. Ward, and P. Webster. *The Anatomy of a Context-Aware Application*, In Proc. 5th ACM MOBICOM Conf., pages 5968, Seattle, WA, August 1999.

Crossbow Technology, [www.xbow.com](http://www.xbow.com).

E. Elnahrawy, X. Li, and R. P. Martin. *The Limits of Localization Using Signal Strength: A Comparative Study*, In IEEE Sensor and Ad hoc Communications and Networks Conference (SECON 2004), Santa Clara, CA, October 2004.

Trolley Scan (Pty) Ltd. *RFID-Radar*, Trolley Scan (Pty) Ltd, Johannesburg, South Africa.

I. Everts, N. Sebe, G.A. Jones, *Cooperative Object Tracking with Multiple PTZ Cameras*, International Conference on Image Analysis and Processing, September 10-14, Modena, Italy, (2007).

M. Sugano, T. Kawazoe, Y. Ohta, and M. Murata, *Indoor Localization System using RSSI Measurement of Wireless Sensor Network based on ZigBee Standard*, Wireless and Optical Communication MultiConference, 2006.

D. Lymberopoulos, Q. Linsey, and A. Savvides, *An Empirical Characterization of Radio Signal Strength Variability in 3-D IEEE 802.15.4 Networks using Monopole Antennas*, In Proceedings of Third European Workshop on Wireless Sensor Networks, Springer Berlin, Heidelberg, Jan. 2006, pp.326-341.

D. Lymberopoulos and A. Savvides., *Xyz: A motion-enabled, power aware sensor node platform for distributed sensor network applications*. In IPSN, SPOTS track, April 2005.

<http://www.x10.com>

<http://www.phidgets.com>