

LOCALIZATION TECHNIQUE BASED ON TIME DIFFERENCE OF ARRIVAL
FOR TRACKING APPLICATION IN WIRELESS SENSOR NETWORKS

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Sesi Pengajian :

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By the name of Allah the Most Gracious, Most Merciful

I would like to dedicate my report for my beloved father and mother, family members and my supervisor

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Thank you.

ABSTRACT

Wireless sensor networks (WSNs) consist of massive low power, low cost and low capability of sensor nodes. WSNs can be applied in various applications like event detection, tracking, environmental monitoring and intelligent buildings. In tracking application, the location of the target can be estimated by using trilateration technique based on the known sensor nodes location and parameter measurement such as time of arrival, received signal strength indicator, angle of arrival and time difference of arrival. However due to the nature of wireless signal propagation, the measurement is affected by multipath fading. This leads to uncertainties and inaccurate location estimation. In this project, we propose a Time Difference of Arrival based localization algorithm for WSNs based on linear least square and partial derivatives method derived from the intersection of hyperbolas to estimate the location of a mobile target in the field of interest. The simulations have been done by using Matlab to show the estimate location of the mobile target. The outcomes of this project is the performance evaluation of the developed localization algorithm that are measured in terms root mean square error (RMSE) of the estimated location of the mobile target.

ABSTRAK

Rangkaian penerima tanpa wayar (WSNs) terdiri daripada kuasa besar yang rendah, kos rendah dan nod penerima yang berkeupayaan rendah. WSNs boleh digunakan dalam pelbagai aplikasi seperti pengesanan acara, pengesanan sasaran, pemantauan alam sekitar dan bangunan pintar. Dalam aplikasi mengesan trek, sasaran boleh dianggarkan menggunakan teknik *multilateration* berdasarkan lokasi nod penerima dan ukuran parameter yang dikenali sebagai masa ketibaan, penunjuk kekuatan isyarat penerima, sudut ketibaan dan perbezaan masa ketibaan. Namun disebabkan oleh sifat semulajadi isyarat tanpa wayar, ukuran yang diteruma boleh dipengaruhi oleh laluan sasaran yang datang dari pelbagai arah. Ini menyebabkan lokasi anggaran yang diterima tidak tepat dan jitu. Dalam projek ini, kami mencadangkan bagi menggunakan perbezaan masa ketibaan algorithm menggunakan kaedah kuasa dua terkecil lurus dan pembezaan separa berdasarkan persimpangan diantara hiperbola untuk rangkaian sensor tanpa wayar bagi mengetahui kedudukan anggaran sasaran yang tepat. Simulasi bagi projek ini telah dilakukan dengan menggunakan perisian Matlab bagi menunjukkan lokasi anggaran sasaran mudah alih. Setelah selesai, prestasi algorithm yang dibina diukur dari segi min ralat persegi bagi anggaran lokasi sasaran yang bergerak.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

A wireless sensor network (WSN) is self-configuring wireless sensor devices that are spatially distributed in diverse location. Each sensor node can independently perform some processing and sensing task and communicate to each other in order to forward the sensing information to the central computer. It typically has several parts such as transducer, microcomputer, and transceiver and power source.

The electrical signal is generated by the transducer if it senses the phenomenon of interest. The processing and the storing of the output are done by the microcomputer. The transceiver will receive command from a central computer thus it will transmit the data to it. Each sensor node get power derived from the battery.

WSN have a broad range of application such as environmental monitoring, healthcare application, emergency rescue, surveillance system and target tracking [1]. While the sensor networks are promising in solving many problems, one of the fundamental challenges that still exists is target localization [2]. Recent advanced in wireless sensor networks have led to renewed interest in target localization and thus becoming a hot topic amongst the researcher[3].

Localization technique plays a vital role in many applications that need positioning data such as navigation system and target tracking. If the user fails in getting the accurate data for the target localization, the related application will fails to operate.

During the last decade, a number of positioning algorithms have been proposed for the positioning problem [4].

There are numerous localization techniques that widely used like the ones which are based on Received Signal Strength Indicator (RSSI), Angle of Arrival (AOA), Time of Arrival (TOA) and Time Difference of Arrival (TDOA). To encounter the challenges in WSNs, we decided to use the most prominent fundamental and popular method which is TDOA in order to locate the chosen target.

1.2 Objectives

This project aims to estimate the location of the target in WSN. To achieve this aim, three objectives have been listed as follows:

1. To develop a target localization algorithm in WSN based on TDOA.
2. To increase the accuracy of target localization while estimate the position of an event occurs as accurately as possible by means of changing the location and number of sensor.
3. To evaluate the performance of localization algorithm based on root mean square error (RMSE).

1.3 Problem statement

Localization is one of the most prominent challenges in WSN. Since most of WSN applications depend on accurate location estimation, a straightforward solution is to equip each sensor with Global Positioning System (GPS) receiver that can accurately provide the sensor with their exact location [5]. However, it is not a feasible solution since GPS cannot be implemented if there are obstacles that might block the line of sight of the signal transmit between the receiver and satellite such as mountains or buildings.

Equipping the GPS device is directly proportional to the number of sensor nodes. Since the sensor uses usually in the order of thousands, the production cost of GPS receiver expensive compared to the production cost of sensor nodes. Thus, it will be a serious burden for the deployment of sensor nodes and not cost efficient.

Since one of the sensor node requirement is need to be small, directly embedding the GPS device would enlarge the size of sensor due to size of GPS and its antenna. Sensor nodes have a longer lifespan and known to be deployed without replacing any sort of battery for many years. However, GPS receiver is not energy efficient. In consequence, it can drain the sensor node battery very fast and reduces the effective lifetime of the networks.

Even though there are many existing techniques have been introduces, yet the measurement estimation still can be affected due to the nature of wireless signal propagation such as multipath fading that can cause uncertainty in estimated target location. The received signal also can be influenced by the random noise produced by the signal itself since the sensor is moving in random pattern. Moreover, the distance measurement noise and Gaussian White Noise also contribute in the signal propagation loss. All of them might cause some delay in time of arrival of the signal that lead to the inaccurate value for the next computation in order to estimate the location of real target.

1.4 Scope of works

According to whether or not the networks need to measure the actual distances between network nodes and based on whether accurate ranging is required, Wireless Sensor Networks can be divided into two categories which are Range-Based technique and Range-Free technique [6]. In this work, Range-Based technique has been chosen and mainly this work focus on Time of Arrival (TOA) and Time difference of Arrival (TDOA) to estimate the sensor node position. There are some basic assumptions have been made in order to accomplish the goals:

- i. The coordinate of the sensor nodes is known.
- ii. The location of the target is unknown and to be estimated.
- iii. All sensors are synchronized with respect to time.
- iv. Only one target at one time.
- v. Focus on 2-dimensional area that works on flat terrain.

1.5 Report Structure

The first chapter of this report gives a brief explanation on the project background, problem statement, objectives and scope of works. Chapter 2 makes clear on the literature reviews of the proposed solution that have been used in a past few years. Chapter 3 describes the project methodology and the next following chapter discusses and analyses the simulation results for the proposed algorithm. Lastly, the conclusion and future work are stated in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Wireless Sensor Networks

A WSN refers to a group of distinctive transducer with a communication basis for monitoring and recording the physical condition at the specified area or network field. Nowadays, they have gain a world-wide attention due to the enormous potential in many applications. Briefly examine their history, WSNs had been widely implemented in military and heavy industrial application. In 1950s, the United States Military successfully developed Sound Surveillance System (SOSUS) which the first wireless network that resembles the modern WSNs to detect and track the Soviet submarines[7]. This network used hydrophone acoustic sensor submerged and distributed in the Atlantic and Pacific Oceans.

Later, the market demand for the WSNs become so strong and they moved beyond their limited application and it is seems to be a great challenge. To meet this demand, a lot of changes have been introduces over the years resulting in robustness, better efficiency and low cost devices that have an ability to store and process data with a superb effectiveness and reduces power intake.

WSNs operate by passing the data through the network to main location or known as a sink where the data can be analysed and observed. A sink acts like an interface between user and the network. WSNs consist of hundreds node that can communicate with each other using radio signals. These wireless sensor nodes equipped with the following components; sensing and computing devices, radio transceivers and power components. Figure 2.1 shows the architecture of a sensor node.

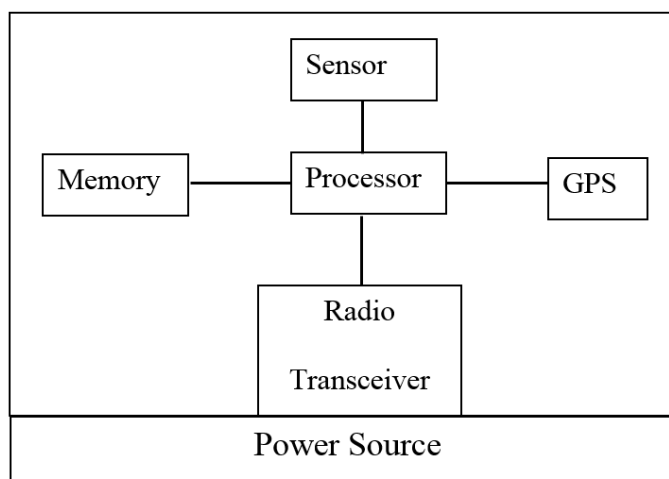


Figure 2.1: Sensor node architecture

The function of the processor is to plan and carry out the task, process the data information's and control the other components in sensor nodes. There are several processors that available for the sensor nodes such as Microcontroller, Digital signal processing (DSP), Field Programmable Gate Array (FPGA) and Application Specific integrated Circuit (ASIC). Since a microcontroller is characterized by its low price, ease to attach other devices, simplicity in programming, they are used in sensor nodes[8] [9].

Microcontroller contains embedded memory that sufficient to store the project. When the sensor measures the information, it depends on the application necessities and outside elements number of information gathered by sensor varies. Presently from the information gathered need to put away and cast only the vital information must be sent to the base station or cluster heads. The transceiver is a combination of a transmitter and receiver. Transceiver responsible to sends and receives message wirelessly. There are many types of wireless transmission media like Radio frequency (RF), Laser and Infrared.

After the sensor nodes are deployed, they start their duty in collecting information of interest. They also respond toward the instruction given from the control site to perform specific function or provide sensing samples. The sensors may include temperature sensors, light sensors, humidity sensors, acoustic sensor or many other sensors. In wireless sensor network, the main power source energy is the battery power. So power unit supplies the battery power to sensor node [10].

2.2 Tracking Application in Wireless Sensor Networks

In tracking application, there are two types of mode available for the sensor nodes which are active mode and inactive mode. Active mode is when the sensor nodes can sense the target at the certain period while when the sensor nodes in sleep state which means they are saving their energy until the target approach them called as inactive mode [11]. As the target moving, the sensor must continuously in active mode.

So, there are some standard of tracking protocol that had been used in WSNs. To summarize, the Figure 2.2 shows the types of tracking protocol that can be used to estimate the location of mobile target.

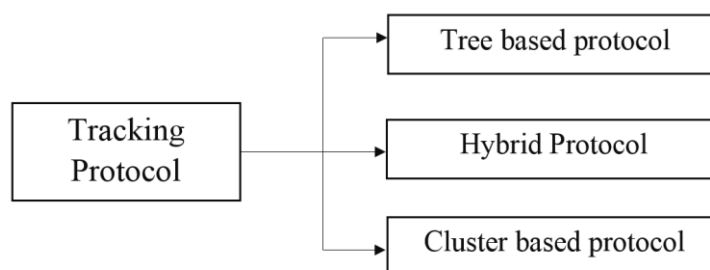


Figure 2.2: Tracking protocol in WSNs

In tree based protocol, the nodes are orderly arranged in hierarchical tree structure. When the tracking takes place, the sensor nodes will communicate with each other to determine the root node. Usually, the root node is a node that happen to be near with the target. Even though, the accuracy of this protocol is higher but it is resulting higher energy consumption.

Due to this fact, when the new node is added, the old ones will be removed to reduce some energy consumption [12]. There are some example of the tree based tracking which are Dynamic Object Tracking (DOT), Scalable Tracking Using Network sensors (STUN), Dynamic Convoy Tree Based Collaboration (DCTC) and Deviation Avoidance Tree (DAT).

Next is cluster based protocol. It is a group leads by the cluster head and group members (sensor nodes). Cluster based protocol can be divided into two which are static clustering with a fixed coverage area and number of sensor node and dynamic

clustering where the sensor will volunteer to function as the cluster head when it detects any target movement.

For static cluster, they faces a boundary problem which block them in sharing information with other group of static clustering whereas in dynamic clustering is high energy consumption since there is repeating of clustering process although it is efficient way to locate the target tracking[13]. Prediction Based or Proactive Clustering and Non Prediction Based Clustering is division of Static clustering and Dynamic Clustering consist of Information Driven Sensor Querying (IDSQ), DELTA and RARE.

Hybrid based protocol is a combination of one or more type of target tracking algorithms, for example the Dynamic Clustering for Acoustic Tracking (DCAT) and Hierarchical prediction strategy (HPS). HPS is formed using the Voronoi division and Least Square Method to estimate the next target location. In DCAT, Voronoi Diagram functions to form the cluster. If the cluster head detects the higher signal strength which exceed the pre-determined threshold, one active cluster head is formed.

Then, it will send a broadcast packet to request the neighbour sensor to join the cluster. The sensor can make the choice whether to accept or reject the request based on the distance estimation between target and themselves. Lastly, cluster head will carry out the localization method to estimate the target location based on the sensor replies before send the final result to sink[14].

2.3 Localization Techniques

Nowadays a lot of different technologies had been used like ultrasonic, infrared and received signal strength for localization algorithm along with localization methods which are Received Signal Strength Indicator (RSSI), Angle of Arrival (AOA), TOA and TDOA[15]. Figure 2.3 below shows the overview of localization method.

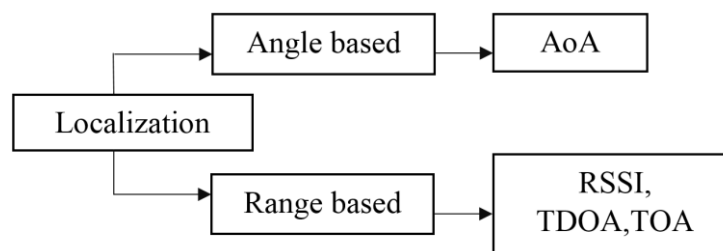


Figure 2.3: Overview of localization

Of the several methods, AOA is a method that operates based on the angle between the propagation direction of incident waves and some reference direction. Firstly, an array of sensors and signal processing technique are employed to estimate the angle between the sensor nodes and the target. Secondly, the approach is followed by doing hybrid combination between RSSI and AOA to obtain the result with higher accuracy but unfortunately AOA is suffering from limitation due to multiple antennas requirement thus increase the cost of limitation.

Then, RSSI is an indicator used at the sensor nodes to determine the strength of received signal. RSSI technique depends on the angle of measurement and noise of environment cause hard to acquire an accurate position. They implementation of this method can be classified into two types which are range-free and range based technique.

If they used the connectivity of data to get the information about target positioning without acknowledge the distance to the target, it is range-free method. On the other hand, if it is only depends on the nodes to estimates the position of the target thus acknowledge the distance to the target, it is range-based method [16]. As advantages, this method has lower accuracy especially for the indoor environment especially in the region near the walls.

TOA is a travel time between the transmitters to the receiver. TOA need at least three sensors so that the location can be found at the intersection of the three circles around the sensor. But TOA technique required the synchronization between transmitter and receiver made it is hard to deploy [8][17]. From TOA, we can make a simple hypothesis that the travelling time shorter as the distance between transmitter and receiver is decreased.

TDOA is very similar to TOA in order to measure the distance, it uses the travel time between transmitter and receiver besides using travel time between each sensor to locate the event occurs. In this project, we decided to use the TDOA based on the previous literature study in choosing the best technique to locate the estimate position of an event occurs and widely been used in navigation and positioning system[18].

2.4 Fundamental of Hyperbola

To get a better clarification, we need to know the basis fundamental of hyperbola. Based on the Figure 1, let's consider a hyperbola with the transverse axis aligned with the characteristic equation as in (1)-(3).

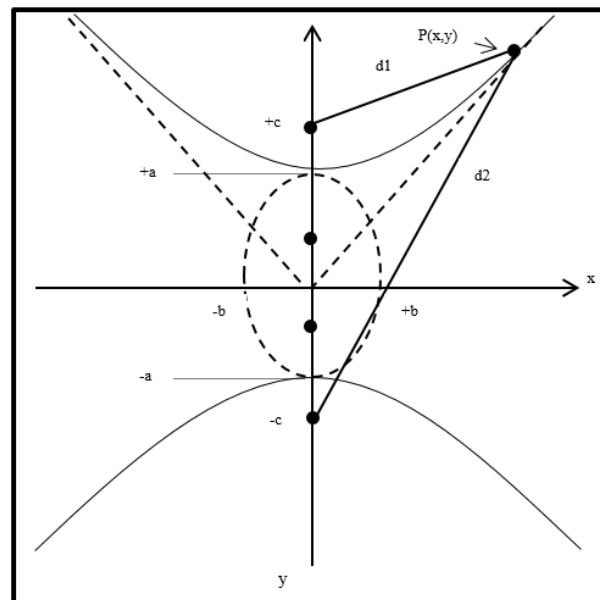


Figure 2.4: Geometry of Hyperbola

$$\frac{y^2}{a^2} - \frac{x^2}{b^2} = 1 \quad (1)$$

$$a^2 + b^2 = c^2 \quad (2)$$

$$|d_2 - d_1| = 2a \quad (3)$$

where:

a: The distance from either vertex to the centre

b: The length of the perpendicular segment between each vertex and the asymptotes

c: The distance from either focus points to the centre