CHAPTER I

INTRODUCTION

1.1.Background

As the Internet of Things (IoT) continues to evolve rapidly, Location-Based Services (LBS) have garnered growing interest and widespread adoption in various industries. Among the promising technologies for location detection and communication is Ultra-Wide-Band (UWB). UWB is recognized for its ability to deliver highly accurate positioning, especially in Line of Sight (LOS) scenarios, where techniques like centroid and trilateration are commonly employed for precise location estimation [1]. Furthermore, UWB has broad applications, including indoor localization of robotic movements and its integration into technologies such as Wi-Fi, ZigBee, UHF, and Smart Home systems [2].

Positioning refers to the process of accurately identifying the location of a person, device, or object. It has become an increasingly active field of research, focusing on using existing technologies to tackle the challenges of improving positioning accuracy. Positioning systems are generally categorized into two types based on the environment: Indoor Positioning and Outdoor Positioning. Outdoor positioning is typically used in open environments, such as determining the location between power lines or across buildings. Global Positioning System (GPS) is the most utilized technology for outdoor positioning due to its capability to deliver precise location data in outdoor settings. However, GPS faces considerable limitations when used indoors, as its satellite signals struggle to penetrate walls and other solid obstacles. To address indoor environments, other positioning technologies such as Ultra-Wide-Band (UWB) or Wi-Fi have been developed to overcome these challenges.

In contrast, Indoor Positioning refers to the process of determining the real-time location of objects within indoor environments. This technology employs a variety of methods that differ in terms of accuracy, cost, precision, scalability, and the underlying technology used, along with system robustness and security considerations [3]. The advancement of indoor positioning systems plays a crucial role in several applications, such as asset tracking, indoor navigation, and smart home solutions, which demand highly accurate positioning despite the presence of physical barriers or obstructions.

Ultra-Wide-Band (UWB) technology offers the advantage of transmitting signals at low power levels, significantly reducing the likelihood of interference with other systems that operate within the same radio frequency spectrum. This characteristic makes UWB an ideal choice for positioning applications in environments with dense wireless technologies. In a UWB-based positioning system, a minimum of three anchors and one tag is necessary to accurately determine the location of an object on a two-dimensional (2D) plane. Each component is equipped with a UWB transceiver, enabling the use of various distance measurement techniques between the anchors and the tag. One widely adopted technique is Two-Way Ranging (TWR), which measures the round-trip time of a signal traveling between the tag and the anchor to calculate the distance. Once the distances between the tag and the respective anchors are determined, classical positioning algorithms like trilateration are employed to geometrically estimate the tag's coordinates. Trilateration requires distance data from at least three anchors to compute the position of the tag in a 2D space. However, in practical applications, various factors such as signal noise, multipath interference, and environmental obstructions can impact the accuracy of distance and location measurements [4].

An example of positioning technology implementation that demands a high degree of accuracy is Real-Time Kinematic (RTK), frequently utilized in applications requiring precise measurements. For instance, The IndiCar App serves as an outdoor RTK implementation, commonly employed in car racing to accurately determine vehicle positions in real time. In contrast, indoor applications of positioning technology can be observed in robot vacuum cleaners, which rely on precise navigation systems to efficiently map and clean designated areas with high accuracy [5].

Another study highlighting the effectiveness of indoor positioning technology was conducted by Gita Indah Hapsari, who explored the use of Ultra-Wide-Band (UWB) with an ESP32 module for indoor positioning, employing the Time Difference of Arrival (TDOA) and Trilateration techniques. Her research demonstrated that incorporating regression analysis in the positioning process can significantly reduce measurement errors. The findings revealed that the Mean Absolute Error (MAE) could be reduced from 79.98 cm to 5.05 cm with the application of regression. Additionally, in the trilateration-based positioning method, the MAE was found to be 8.15 cm on the X-axis and 8.47 cm on the Y-axis. These results indicate a notable improvement in the accuracy of indoor positioning measurements, further affirming the potential of UWB in delivering high-precision location data in challenging indoor environments. This research provides valuable insights into the ongoing development of more reliable and accurate indoor positioning systems, especially in scenarios where precision is critical [6].

Study about SVR, the paper demonstrates the effectiveness of Support Vector Regression (SVR) in enhancing positioning accuracy in RFID-based systems, particularly due to its ability to handle non-linear relationships and multicollinearity, which are common challenges in such environments. By integrating SVR with the LANDMARC algorithm and applying a Gaussian-Kalman filter to smooth RSSI signals, the authors significantly improved positioning accuracy. The SVR-LANDMARC algorithm achieved a root mean square error (RMSE) of 20.243 cm, outperforming the original LANDMARC, which had an RMSE of 35.532 cm, highlighting SVR's capability to reduce errors in indoor positioning [24].

Previous studies have reinforced the potential of Ultra-Wide-Band (UWB) technology in indoor positioning systems, particularly when combined with advanced methods such as regression, which effectively reduce measurement errors and enhance accuracy. While another one, reinforced about how accurate SVR detects the position. Building upon these findings, the objective of this study is to further improve the accuracy of distance measurements under Line of Sight (LOS) conditions by utilizing UWB technology and the Support Vector Regression (SVR) method. UWB is selected for its capability to deliver high-resolution distance measurements, while SVR is employed to model the non-linear relationships between signal parameters and measured distances. By integrating these two approaches, the study aims to achieve more precise distance measurement results, particularly in LOS scenarios within indoor environments.

1.2.Problem Statement

Based on the background, this research identified the problem which focused on enhancing indoor positioning accuracy in Line of Sight (LOS) conditions by utilizing Ultra-Wide-Band (UWB) technology and implementing the Support Vector Regression (SVR) algorithm. This problem is articulated into the following refined scientific queries:

1. How to develop methodology to enhance the accuracy of indoor positioning in Line of Sight (LOS) conditions?

2. How far does Ultra-Wide-Band (UWB) technology be effectively utilized to improve indoor positioning accuracy?

3. Does the integration of the Support Vector Regression (SVR) algorithm with UWB technology could enhance positioning accuracy in LOS conditions indoors?

1.3.Research Objectives

Based on the identified problem statements, the objective of this study is to develop a more precise positioning method for Line of Sight (LOS) conditions in indoor environments by assessing and optimizing the use of Ultra-Wide-Band (UWB) technology. Furthermore, the study aims to implement and evaluate the effectiveness of the Support Vector Regression (SVR) algorithm on UWB data to enhance positioning accuracy in LOS scenarios indoors, with the goal of minimizing error to within 20 cm.

1.4.Scope of Work

The scope of this research encompasses several key areas aimed at enhancing positioning accuracy under Line of Sight (LOS) conditions in indoor environments, as detailed below:

1. The study will initially focus on Ultra-Wide-Band (UWB) based positioning systems designed for indoor environment by considering various factors that influence accuracy, such as distance, frequency, and signal interference.
2. Additionally, the research will explore the performance of UWB technology, evaluating its effectiveness to identify optimization opportunities in positioning systems. This analysis will be conducted in an 8x5 meter room with 22 coordinate points, specifically under LOS conditions.
3. Finally, the research will explore the application of the Support Vector Regression (SVR) algorithm to the data obtained from UWB technology. SVR will be used to model and predict positions with enhanced accuracy. The effectiveness of SVR in improving positioning accuracy will be assessed through simulations and experiments, with data collection conducted at each coordinate point over one minute per measurement.

1.5.Research Methodology

The research process and methodology employed in composing this thesis comprises multiple steps organized in a work breakdown structure as follows:

1. Literature Review

   This phase as initial phase involves problem identification and other two approaches which are gathering references from direct observations conducted at the research site and sourcing relevant materials from scientific journals and other related literature. Regarding the issues that will be examined in the study.

2. Dataset Collection

   At this stage, the researchers will independently construct a dataset based on the data gathered from ranging measurement and field observations.

3. Data Analysis

   The collected data will undergo analysis, which includes calculations, computational processes, and the development of programs to process the information.

4. Design Phase

   Following the analysis, the data will be translated into a design that represents the key characteristics in a more comprehensible and interpretable form. This phase will be the key to results.

5. Testing and Results

   In the final stage, after the completion of the program design and models, testing will be conducted to evaluate the accuracy and effectiveness of the models, ensuring that the results meet the study's objectives.

Those research methodologies will be detailed as Work Breakdown Structure (WBS) research in Figure 1.1.

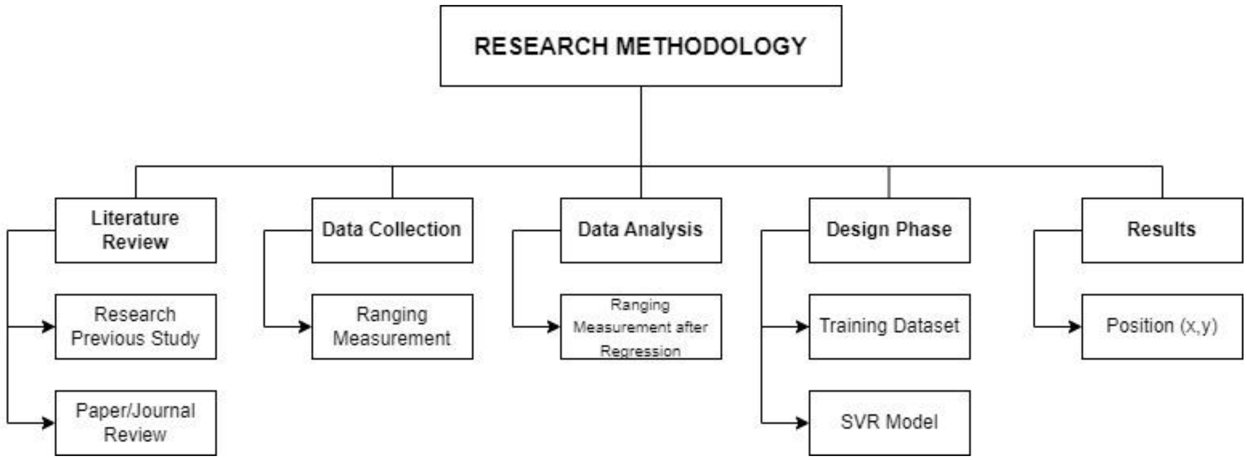

Figure 1. 1 Work Breakdown Structure

1.6.Hypothesis

Based on previous research, these are some points of the following hypotheses which are proposed for this study:

1. UWB Technology Enhances Accuracy
   The Ultra-Wide-Band (UWB) technology can achieve centimeter-level accuracy through the application of the Two-Way Ranging (TWR) technique. This method effectively measures the round-trip time of signal travel between devices, which reduces errors caused by environmental factors, making it ideal for high-precision indoor positioning systems [23].
2. Regression Improves Ranging Accuracy
   Regression techniques, particularly in positioning applications, have been shown to significantly enhance accuracy by refining the relationship between signal parameters and distance. Various studies demonstrate that regression helps reduce noise and errors during the ranging process, ensuring more accurate distance measurements [4, 6, 14].
3. Support Vector Regression (SVR) Enhances Positioning
4. The Support Vector Regression (SVR) method improves positioning accuracy by identifying a hyperplane that minimizes prediction errors. By modeling the non-linear relationships between input data and positions, SVR ensures that the predicted results are as close as possible to the true values, while maintaining a certain margin from all

data points. This helps enhance precision in scenarios where signal interference or multipath effects may compromise accuracy [24].

These hypotheses align with the expectation that by combining UWB technology with advanced regression techniques like SVR, significant improvements in indoor positioning accuracy can be achieved.

1.7.Research Timeline

The research timeline for this thesis will be conducted in accordance with the predetermined timeline to ensure timely completion. Figure 1.2. Displays the sequence of stages and descriptions of research effort in this thesis.

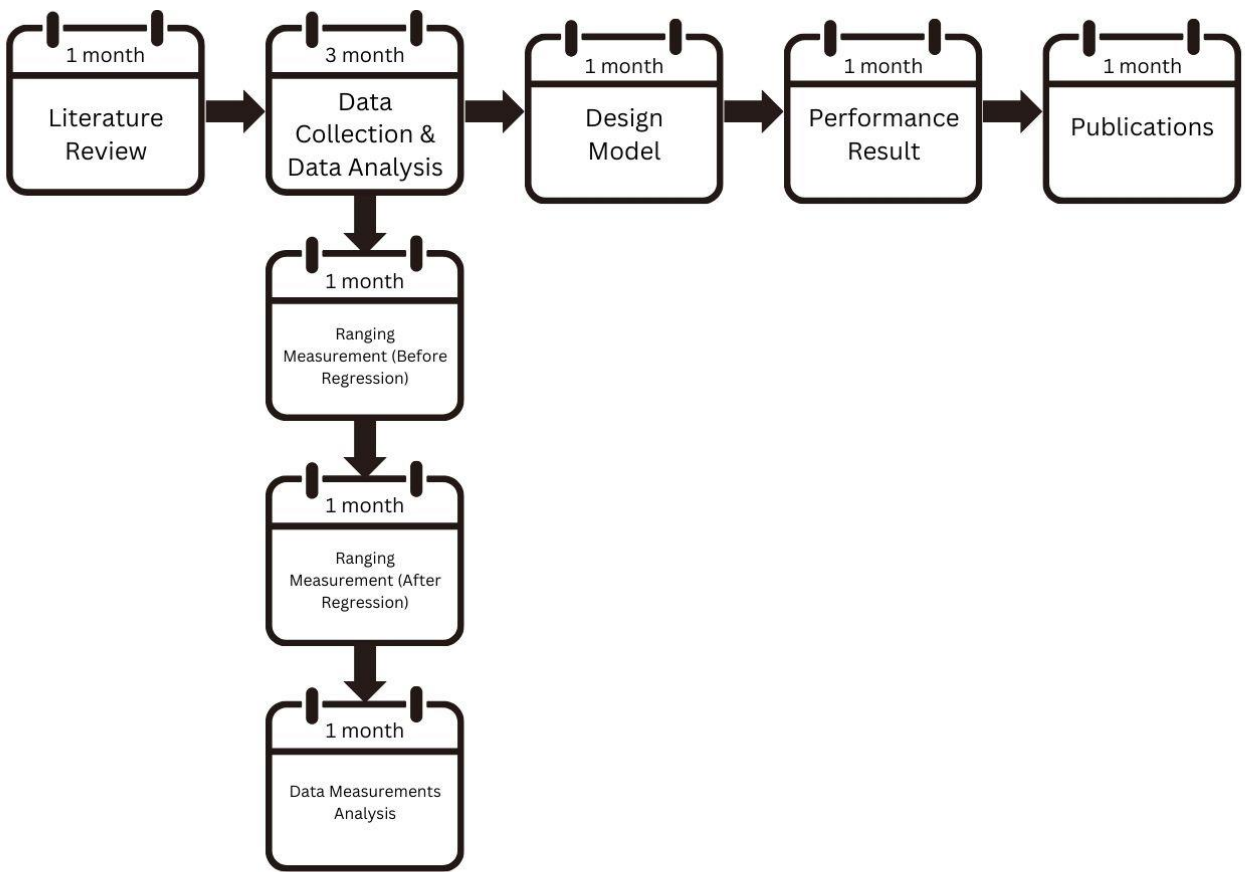

Figure 1. 2 Research Timeline

This research timeline shows the process with time explanation in detail which divided into several key stages, with each step focused on enhancing the positioning accuracy of Ultra-Wide-

Band (UWB) in indoor environments. Literature Review (1 month) this initial phase involves reviewing relevant research, theories, and previous studies to establish a foundation for the experiment. Data Collection and Data Analysis (3 months) In this stage, the researcher collects data related to positioning accuracy and performs an initial analysis to identify key factors affecting performance. Ranging Measurement (Before Regression) (1 month), this stage is included on data collection and data analysis stage. Before applying any regression techniques, initial ranging measurements are taken to assess baseline accuracy in positioning. The next step is ranging measurement (After Regression) that involves applying regression methods to improve the accuracy of ranging measurements, followed by another round of measurement to compare results with the initial data. Data Measurements Analysis (1 month), this stage is comparing data before and after regression process and analyzing it to evaluate the impact of regression on positioning accuracy. Design Model (1 month), based on the analysis, a model is designed to improve positioning accuracy using refined data. Doing a performance result is evaluating the model's performance to ensure the accuracy goals are met. Hence, the results of the study are documented and prepared for publication to share the findings with the scientific community.