# CHAPTER I
# INTRODUCTION

## 1.1 Rationale

Indoor navigation [1]–[3] plays a very important role in Wireless Fidelity (Wi-Fi) networks [4]–[6]. Due to its ubiquity, IEEE 802.11/Wi-Fi based positioning is becoming the technology of choice for indoor positioning systems [7]–[9]. There are some problems in user positioning, such as to improve the positioning accuracy and robustness [10], [11], many techniques and algorithms have been proposed to solve this issue. Localization techniques in Wi-Fi consists of two categories: the range-based [12]–[15] and range-free method [16]–[19]. The range-based method has higher positioning accuracy and higher complexity than the range-free method [20]–[22]. There are many range-based positioning methods, such as those based on received signal strength indicator (RSSI) [23]–[25], angle of arrival (AOA) [26]–[28], time of arrival (RTT) [29]–[31], and so on [32]–[34]. In range-based localization methods, it consists of two steps in the positioning process: distance estimation and position calculation. In the distance estimation stage, the distance measurement techniques such as RSSI, AOA, and RTT are used to estimate the distance. More than one distance value will be calculated from nearby available access points. After obtaining a series of distance values, in the second stage: the position coordinates will be determined from distance values by localization algorithms.

Indoor positioning system in the field of navigation used localization parameters, such as distance estimation like received signal strength (RSS) that susceptible to noise and angle estimation (AOA) that susceptible to shadowing effects [35]. AOA have high accuracy but requires additional hardware like antenna arrays that makes it hard to implement especially for devices in indoor environment. While RSS is easy to implement and eliminates energy consumption, round-trip time (RTT) reduces complexity, enhances reliability, have high range measurement and update rate [36].

By using the measurements of the round-trip time (RTT), modified trilateration with least square are proposed to geometrically locate the user position on the public dataset [37]. In the dataset, the access points have coplanar Z-axis. The coplanar of coordinate location of the access points scheme has been limiting the adverse possible scenarios of access points locations, with multiple measurements of the RTT, user Z-axis location can be derived. For example, in indoor localization problems, the anchors may be placed near the ceiling to secure the line-of-sight (LOS) against obstacles. Also, automated laser scanner [38] with coplanar beacon placement, and localization using least squares technique of adjustment of indirect observations.

In this paper, a modified 3D localization algorithm is proposed to solve the unsolvable coplanar access points problem to estimate user position. The algorithm utilizes the RTT range-based localization and includes two phases. The concept of establishing a modified matrix-A affected by the coplanarity is added. And the user position is determined based on the 4 distance equations is selected to solve the coplanar axis problem. Thus, the user position can be estimated in the coplanar access points scenarios. Finally, the performance of the method is verified and compared with trilateration algorithm that has no coplanar access points problem. The user estimated position and user true position are calculated to obtain Root Mean Square Error (RMSE) of the algorithm The simulation results show that the proposed method outperforms the trilateration algorithm in terms of positioning accuracy.

Following is a summary of the key contributions:

(i) The conventional trilateration with least square algorithm is modified. The algorithm consists of 2 stages, to solve the unsolvable coplanar access points problem to estimate user position.

(ii) The modification of matrix-A equation is proposed to avoid the null result in estimated user position. So, the X-axis and Y-axis of the user position can be estimated.

(iii) The idea of using the Z-axis from the nearest distance between the mean and the 4 distance equations of the access points is proposed to estimate the user Z-axis position. Where this was a problem before, caused by a coplanar access points problem.

(iv) The simulation shows that modified trilateration with least square method algorithm can be used to solve the coplanar access points problem to estimate user position.

(v) Compared the performance of the proposed algorithm with trilateration in geometry in simulation with the same public dataset.

The rest of the paper is organized as follows. In Second 2, the three-dimensional localization model and related work presented. In Section 3, a modified trilateration with least square method is explained. In Section 4, a report of the simulation results is explained. Then, Section 5 is the conclusion and a prospect for further work.

## 1.2 Theoretical Framework

In December 2016, the IEEE 802.11 working group ratified amendment 802.11-REVmc (also referred as IEEE 802.11mc) for the Wi-Fi standard, which included a new two-way ranging capability based on time of flight (ToF) of Wi-Fi packets to improve the positioning accuracy. Where the recipient responds to a fine timing measurement (FTM) with an acknowledgement packet, and the transmission and reception times of each are recorded FTM frame. It seems like a ping-pong protocol that calculates ToF by measuring the time it takes for a packet to be sent from an access point to a mobile and then back again.

This measurement approach is based on the TOF and develops to solve the synchronization problem subjected to the use of TOA. The RTT measurement does not need the clock synchronization between the nodes. This means less complexity and high reliability. In addition, the ranging error and range between a couple of devices are nearly independent when the clock operates at the same rate on the nodes. The FTM can give a large range estimation and a large update rate compared to the scene analysis system. However, the RTT ranging measurement has limitations with respect to its reflection, fading, shadowing, and unstable clock speed due to phase noise as well as a different processing time delay. Moreover, the FTM protocol has a concurrent processing capacity problem, and an access point cannot concurrently reply to higher amounts of FTM inquiries.

## 1.3 Conceptual Framework

After getting the distances between unknown nodes and anchor nodes, we can estimate the location of unknown nodes through the distances and location of anchor nodes. In the process of positioning, the combination of anchor nodes which can determine an unknown node through multilateral localization is called a positioning unit.

In the two-dimensional plane, a positioning unit consists of at least three anchor nodes. When calculating the location of the unknown node through trilateration, it is impossible to locate the unknown node when the three anchor nodes are in a straight line or collinear.

The same problem also exists in the three-dimensional space. A positioning unit in the three-dimensional space requires at least four anchor nodes. Due to the error of RTT measurement, four spherical surfaces do not necessarily have an intersection point. In addition, it is hard to locate the unknown node when the four anchor nodes are almost coplanar. And it is impossible to locate the unknown node when the four anchor nodes are coplanar. To solve the unsolvable problem of coplanarity, we proposed a modified trilateration with least square method.

## 1.4 Statement of Problem

In the two-dimensional plane, a positioning unit consists of at least three anchor nodes. When calculating the location of the unknown node through trilateration, it is impossible to locate the unknown node when the three anchor nodes are in a straight line or collinear. The same problem also exists in the three-dimensional space. A positioning unit in the three-dimensional space requires at least four anchor nodes [39]. Due to the error of RTT measurement, four spherical surfaces do not necessarily have an intersection point. In addition, it is hard to locate the unknown node when the four anchor nodes are almost coplanar. And it is impossible to locate the unknown node when the four anchor nodes are coplanar.

## 1.5 Research Objective

Our method considers the unsolvable coplanar access points problem and uses the modified trilateration with least square method to solve this problem. Then, rule out the possible estimated Z-axis user position from coplanar Z-axis access points and get the best user estimated position value.

## 1.6 Hypothesis

The unsolvable coplanar access points problem can be solved by using the modified trilateration with least square method.

## 1.7 Research Methodology

In Figure 1.7.1., we showed the research method to consider the coplanar problem in trilateration with least square method. Modified trilateration with least square method algorithm was developed from the original of trilateration with least square method and Pythagoras equation. Where there are at least four APs for coplanar APs scenario.

Then, Wi-Fi based on RTT simulation scenario was designed to analyze trilateration with least square algorithm positioning accuracy with parameters such as root mean square error (RMSE).

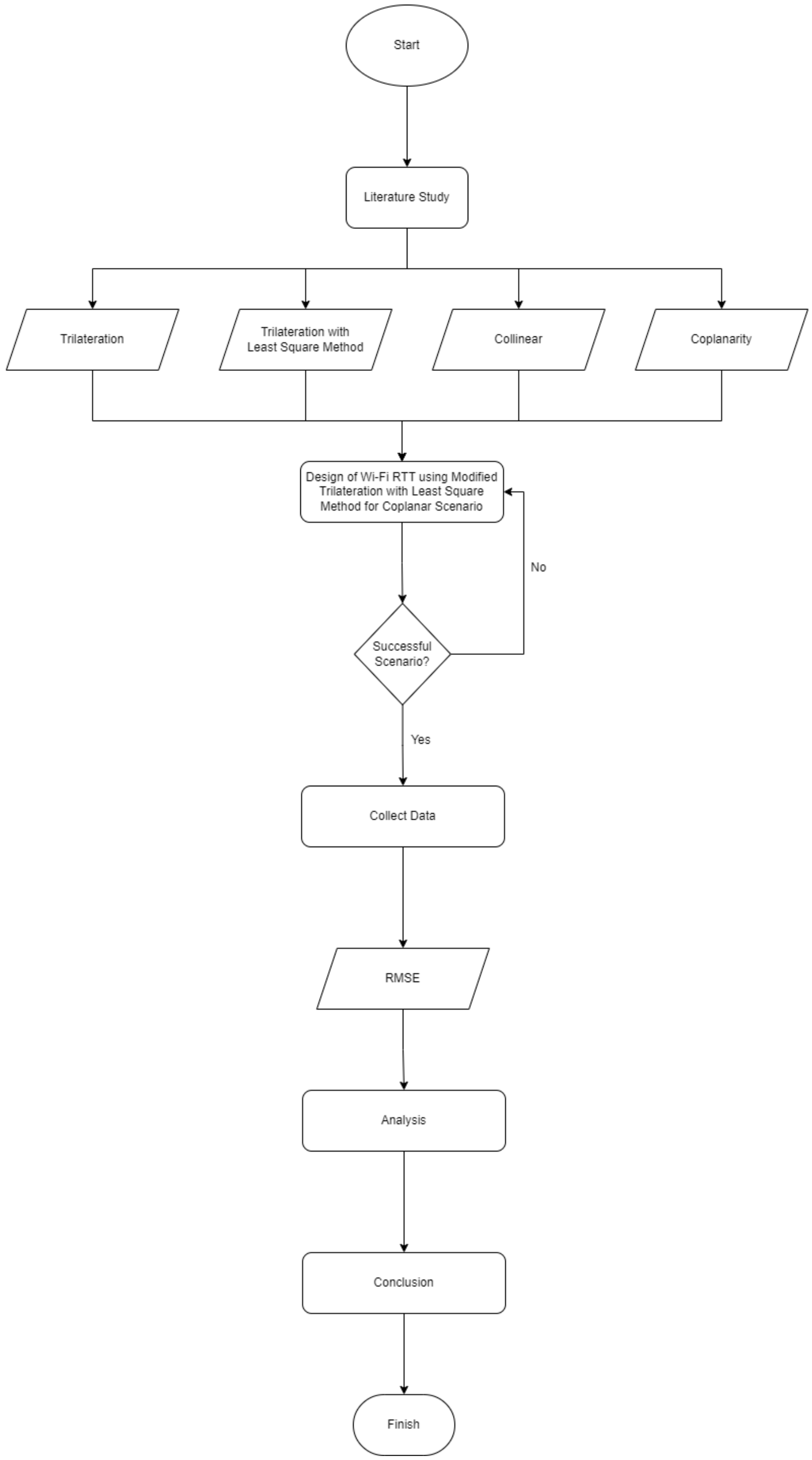


**Figure 1.7.1.** Modified trilateration with least square method research methodology.

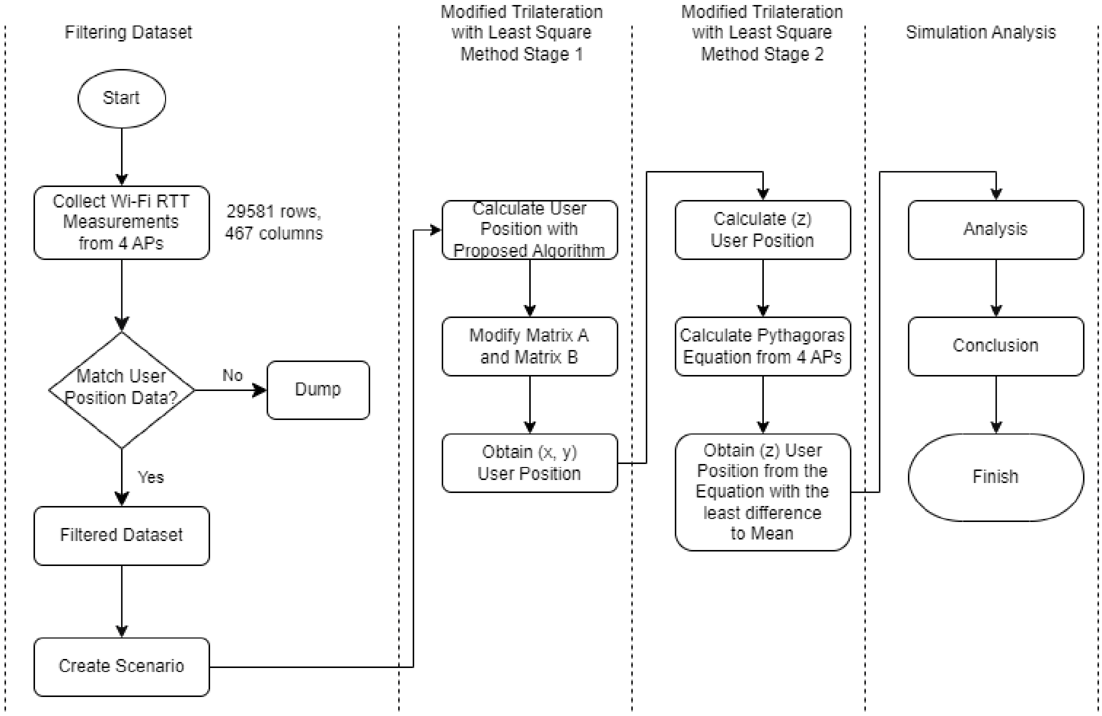


**Figure 1.7.2.** Modified trilateration with least square method flowchart.

In Figure 1.7.2, we showed our proposed Modified trilateration with least square method flowchart. The process started with filtering dataset from the public dataset [37]. In the public dataset, there are 467 columns or 467 features. We dump 367 out of 467 features, because these are the CSI features. Next, we match user position data, which are the Ground Truth of (x, y, z) axis of user position based on the pairing of 4 APs data. After filtering data, we have (91 rows, 10 columns) data. From 10 features or 10 columns, we don't use timestamps feature since it's useful for machine learning not conventional algorithm. Because our distance measurement was based on RTT, we don't match the data by the timestamp, instead we match the data based on the Ground Truth (x, y, z) user position. We only use 9 features, which is Ground Truth X user position, Ground Truth Y user position, Ground Truth Z user position, Ground Truth X AP position, Ground Truth Y AP position, Ground Truth Z AP position, estimated distance from AP to user, Ground Truth distance from AP to user, and AP number.

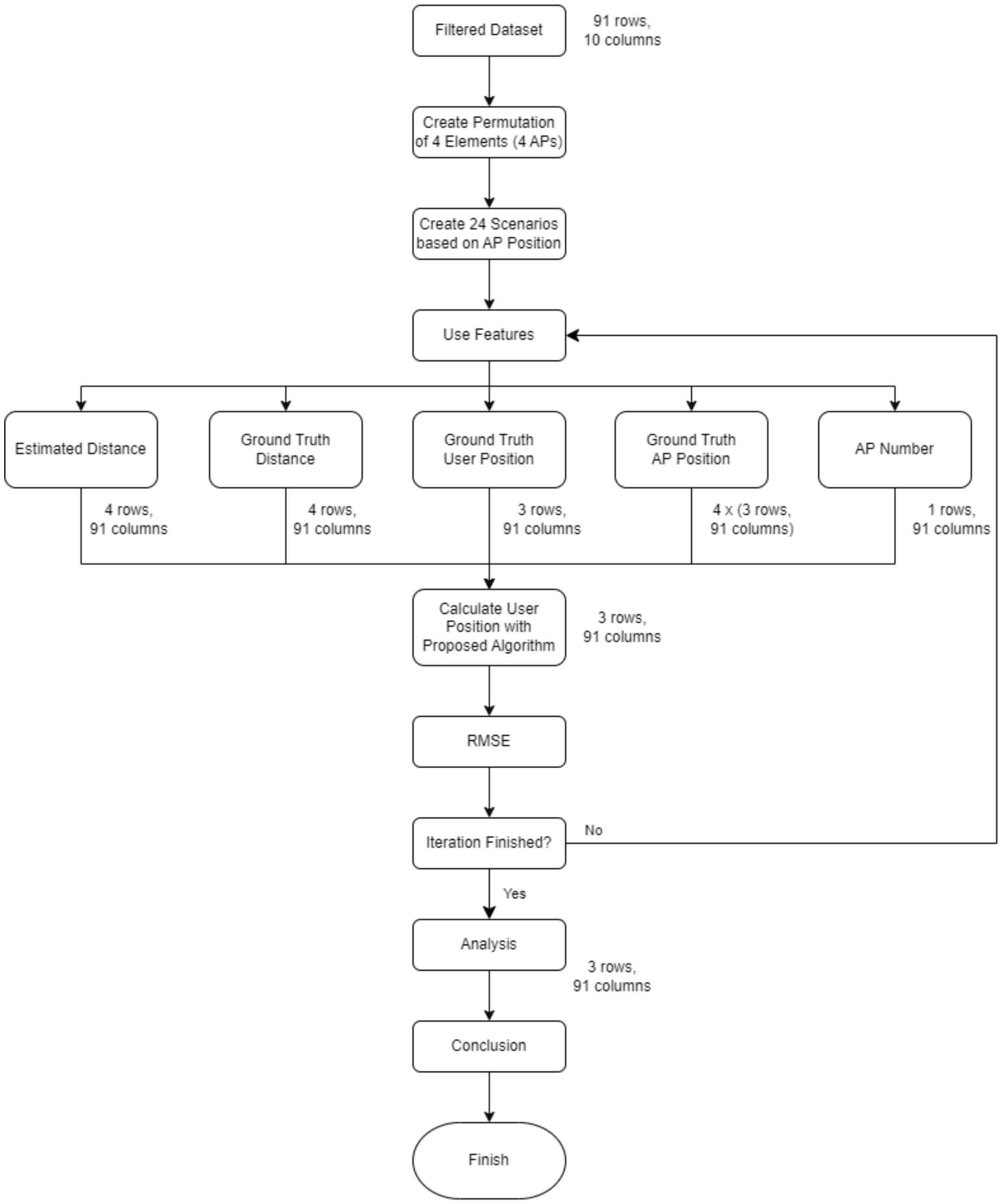


**Figure 1.7.3.** Create Scenario flowchart.

In Figure 1.7.3, we create scenario based on permutation of 4 elements (4 APs). Based on this permutation, there are 24 combinations. Hence, we create 24 scenarios for the simulations. After that, we used features such as estimated distance (4 rows, 91 columns), Ground Truth distance (4 rows, 91 columns), Ground Truth user position (3 rows, 91 columns), and Ground Truth AP position (4 x (3 rows, 91 columns)). Then, calculate user position (3 rows, 91 columns) with the proposed algorithm. Although, in the user position calculation, we only used estimated distance and Ground Truth AP position. The positioning accuracy defined as RMSE is the result for the simulation. There are 91 iterations.

Back to Figure 1.7.2, the proposed algorithm consisted of two stages. In stage 1, calculate user position. Where we modified the matrix A and matrix B equation from the conventional trilateration with least square method. Then, we obtain the (x, y) user position from stage 1. In stage 2, calculate (z) user position. Where we calculate the Pythagoras equation from 4 APs. And obtain the (z) user position from the equation with the least difference to mean of 4 APs. Thus, we obtain the (z) user position from stage 2. Finally, we obtain the (x, y, z) user position from the proposed algorithm. Next, for simulation analysis, after the iteration is completed. The RMSE result of our proposed algorithm is compared to the Ground Truth user position. Then, we analyze the simulation results. And finally, based on the analysis, we make a conclusion of the simulation results.

## 1.8 Research Method

The research method used to implement and evaluate the performance of the proposed triangulateration localization algorithm in indoor positioning system was by doing a simulation of the proposed algorithm with software called MATLAB R2021A in the Wi-Fi based RTT environment using public dataset [37]. The reason we choose this dataset is because, we need APs coordinate location (X, Y, Z) to calculate the user position using the proposed algorithm. And this feature is only available in this dataset. The simulation scenario showed in Sect. 3.2.

## 1.9 Scope and Delimitation

To strengthen the points of concern, the scope of this research is limited to the following:

1. The proposed localization algorithm for indoor positioning system, the modified trilateration with least square method, is aimed to solve the coplanar access points problem, thus making the focus of this research is to enable Wi-Fi-based IPS with modified trilateration with least square method in coplanar access points scenario.
2. The proposed algorithm used RTT information that was from public dataset.

3. The proposed algorithm was simulated with 4 coplanar APs in a three-dimension environment.
4. The access points have coplanar Z-axis, and non-collinear X-axis and Y-axis.
5. The proposed algorithm was simulated in 4 scenarios based on available access points in the public dataset.
6. The proposed algorithm performance was evaluated with RMSE.
7. We compare the proposed algorithm with trilateration in geometry algorithm which does not have a coplanarity problem. And analyse the correlation between the performance and distance measurement error of 4 APs to user based on the dataset. We didn't compare the proposed algorithm with triangulation because triangulation uses angle measurement, not distance measurement. And our proposed algorithm used distance measurement.
8. Since this research focuses on enabling Wi-Fi-based IPS with modified trilateration with least square method in coplanar access points scenario, several consideration aspects in realizing an IPS, e.g., deployment cost, computational cost, and power consumption are not discussed.

## 1.10 Importance of the Study

By doing this research, I view the major contributions that can be delivered are as follows:

1. Enabling Wi-Fi-based IPS with modified trilateration with least square method in coplanar access points scenario was presented in this research. The proposed indoor modified localization algorithm was detailed to motivate more applications of it in other indoor positioning system or even other applications.
2. Extensive experiments are conducted to implement, evaluate, and optimize the performance of modified trilateration with least square method in Wi-Fi RTT using a publicly available dataset which can be accessed in [37]. Hence, we compare our proposed algorithm with trilateration in geometry which does not have a coplanarity problem, to assess the performance in RMSE.