CHAPTER 3

METHODOLOGY

The study aims to design a radio frequency-based indoor localization system using Zigbee technology to evaluate its feasibility and accuracy in tracking a person's position as well as their distance respective to other people's positions. The main objective can be achieved by creating an experimental setup for the Zigbee readers and tags to determine the optimal conditions of the equipment for the system and applying trilateration to RSSI readings for the collection of tag information that will be used to compute distances between two tags in the testing area. The output of the proposed system will be observed through the GUI which will display the map location of tags and distance information.

Conceptual Framework

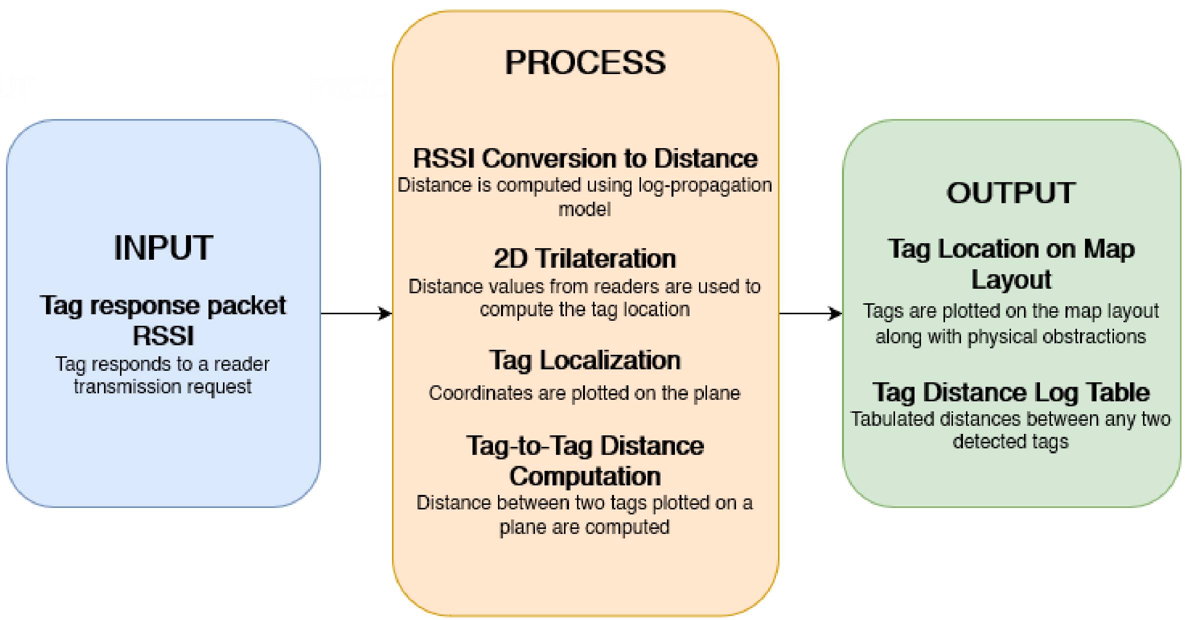

Figure 1. Zigbee-based Localization Conceptual Framework

Figure 1 shows the overview of how the proposed system will process the given input into the expected output. The system input is the signal transmission sent by the tag. Due to its installed lithium-ion battery, it is capable of acting as a beacon which broadcasts a response packet continuously whenever it recognizes a transmission request packet from the readers. Request packets are transmitted by the readers upon booting and will continue to do so even when it receives acknowledgement from the tags. Each reader is placed on the test location in such a way that each reader range overlaps with others. When a response packet is received by the reader, the packet transmission of the tag is sent to the Zigbee coordinator connected to the computer where the information will be imported to MATLAB for processing the information.

First, the signal strength received by each reader from the tag transmission is obtained in the form of decibels to estimate the distance between the tag and a particular reader whenever a tag enters the test location. If a tag successfully sends out its response, each reader is expected to transmit the contents of the tag transmission to the coordinator for data logging and processing. Using the RSSI values received by the coordinator, the location of the tag is computed by using a 2D trilateration algorithm. This process will be applied to other tags that are within the site as well to obtain their respective location.

Since 2D trilateration is used, each computed location can be visualized as points on a plane which is modelled according to the top view of the testing site. Distances between any two tags are then computed. The last step localizes the tag location as actual points on the map layout of the test area. The system output would be the information displayed on the graphic user interface (GUI) such as the map location of the tags, the x and y coordinates of the tag, and the calculated distance with respect to other tags.

Hardware

A. Readers

To conduct wireless communication, the study will utilize XBee S2C modules along with Arduino Uno units for the reader units. These modules operate at 2.4 GHz and run on Zigbee TH Pro function. Its built-in 1mW whip antenna is capable of reaching a maximum of 60 meters in an ideal indoor setting with little to no obstruction to radio signal propagation. Power would be supplied by the AC to DC port of the Arduino Uno which will be plugged to the electrical sockets for the duration of the tests. An XBee shield will be used to mount the XBee module on the Arduino Uno. A total of four readers acting as routers of the network will be constructed using the components to create the localization area by sending packet transmissions to the tags while another XBee module mounted on an XBee Explorer acting as a coordinator will be connected to the computer and receive the RSSI readings. Figure 2 shows the reader upon connecting each component on the Arduino Uno

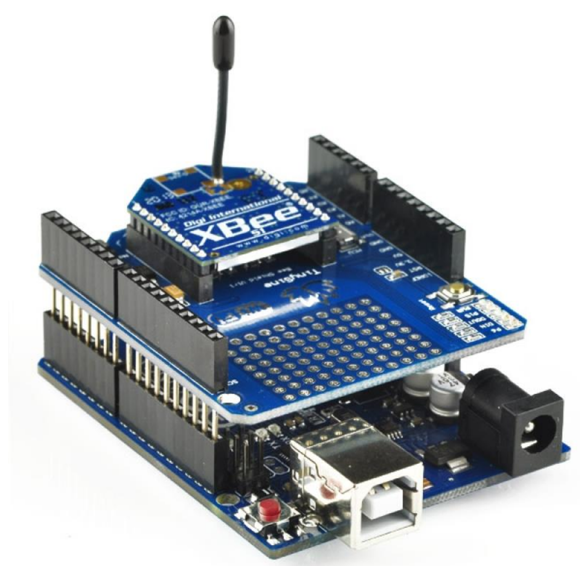

Figure 2. Xbee S2C module and Arduino Uno mounted on shield (Reader Setup)

B. Tags

The study will use active tags for the system to gain a wider signal by using an XBee S2C module on an Arduino Fio microcontroller board which brings its antenna range at the same reach as the reader. Each tag will have an assigned twelve-digit EPC which will provide distinction for each unit as it is monitored during testing and they will represent the location of an individual on the localized area. The Arduino Fio comes with a battery port suitable for lithium-ion batteries with a voltage rating of 3.7 V which will serve as its power port. A total of three active tags will be used for testing the localization accuracy and will act as end devices of the Zigbee network, sending out response packets to the transmissions emitted by the readers. Figure 3 shows the constructed user tag used in the setup.

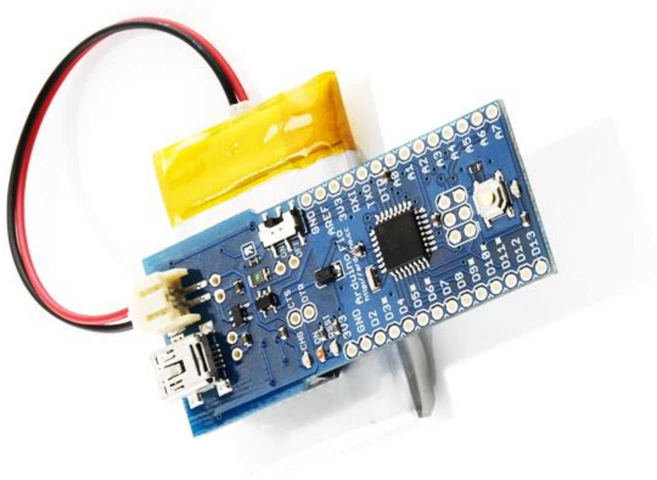

Figure 3. Arduino Fio connected to lithium-ion batteries (Tag Setup)

C. Stands

Stands will be used to secure the desired position and altitude of each reader and tags. To minimize the radio signal obstruction, each stand will be constructed with plastic materials. Height adjustment is also featured to allow variations in reader altitude during optimization and calibration.

Overall Network Design

A. Network Overview

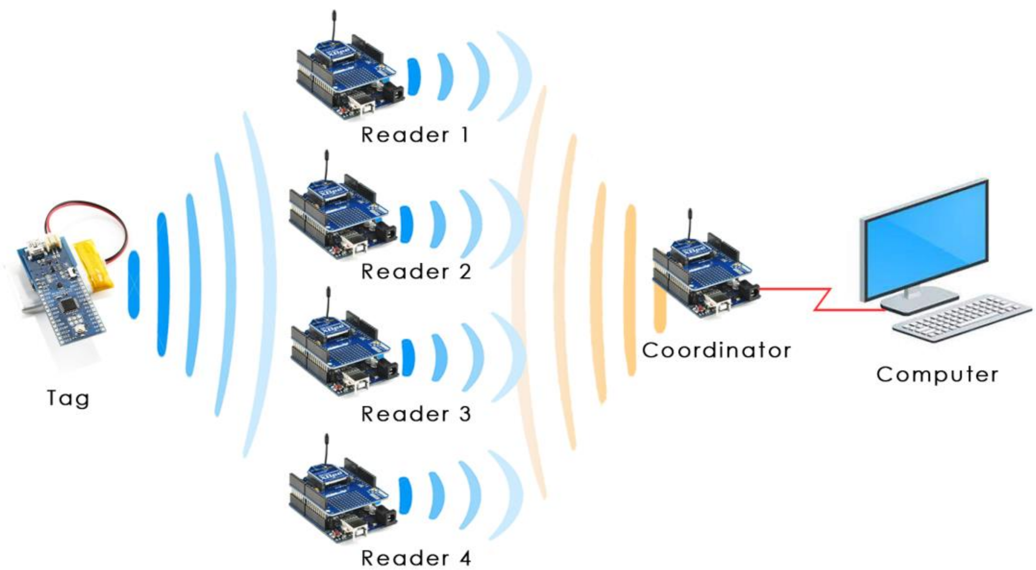

Figure 4. Network Overview of Zigbee-based Localization System

Following Zigbee protocol for XBee S2C module series, the wireless sensor network of the localization system consists of three types of devices namely coordinator, router, and end device. The system shall have one coordinator in serial communication with the laptop that manages and controls all the nodes in the network and will be used for sending data to MATLAB for further processing. The four readers will act as routers of the network since they will be responsible for bridging the tag information to the coordinator. The tags shall be configured as end devices since it only needs to be able to send and receive packets to the readers and coordinator so that the RSSI data needed for the system can be collected.

B. Localization Flow

The flow of communication in the proposed network starts upon powering up the system. First, network association is accomplished in order to have all readers and subject tags connected to one network under the assigned coordinator. This is done by having the coordinator send initialization packets to the readers and tags to which the readers and tags must send back empty packets to confirm a successful connection between the nodes.

After establishing the connections, the next part of the process will be obtaining the RSSI measurements. Interference of signals will be avoided by having the 4 readers conduct RSSI measurements on the subject tag one at a time. Hence, RSSI measurement starts with the coordinator sending out a new packet carrying the command to get the RSSI value and the address of the subject tag to the first reader indicated in the table of connected readers. The reader then sends out an empty packet once again to confirm that the new packet was received and then begins to measure the RSSI of the target address in the packet. When the reader's measurement is complete, it sends the information to the coordinator and the coordinator transmits an empty packet for confirmation and displays the value on the screen. The same process is followed for the succeeding 3 readers. When all RSSI measurements from the 4 readers are complete, the coordinator will then send the RSSI measurements to MATLAB.

Optimization and Calibration

The optimization and calibration for the experimental setup of the readers, antennas, and tags is an important aspect of the study. The context for the proposed indoor localization system is it is meant to be applied in an indoor hallway type of environment wherein the people will be handling active tags that are part of the system to have their positions determined, and consequently, calculate the distances between two people with tags.

In order to simulate the setup as closely as permissible, the testing shall be done in an indoor controlled environment with dimensions 4.1m x 9.0m x 3.0m and chairs will be lined up near the walls in order to resemble a regular hallway. The experimental setup shall consist of 4 readers with built-in whip antennas placed on the four corners of the rectangular area and 3 active subject tags placed in predetermined locations for testing. Part of the experimentation is conducting trials to analyze the signal quality of the system based on the placement and orientation of the readers and subject tags to determine the best setup that will be used for the final indoor localization system for obtaining tag-to-tag distances.

A. Antenna Orientation

Antenna orientation has a significant effect in the obtained values for localization measurements because of the aspect of radiation pattern of antennas which may vary in power and signal strength emitted for different directions depending on the type of antenna. Received Signal Strength (RSS) is an integral factor in acquiring the estimated location of the subject or target which is why it is important to determine the optimal orientation that has the most minimal negative effect on the accuracy of RSS reading.

XBee S2C modules are equipped with 3mW built-in whip antennas which have a radiation pattern that is omnidirectional, meaning it emits signal strength in all directions uniformly. Both reader and tags will be operating using XBee S2C modules only with different configurations. To find the optimal orientation for reader-to-tag, different orientation patterns will be tested on a setup with a fixed distance but different angles between one reader and three tags. Figure 5 shows the five antenna orientations that will be tested and shall be referred to as Orientation 1, Orientation 2, Orientation 3, Orientation 4, and Orientation 5. The shaded circle of the blocks signifies the antenna part of the device.

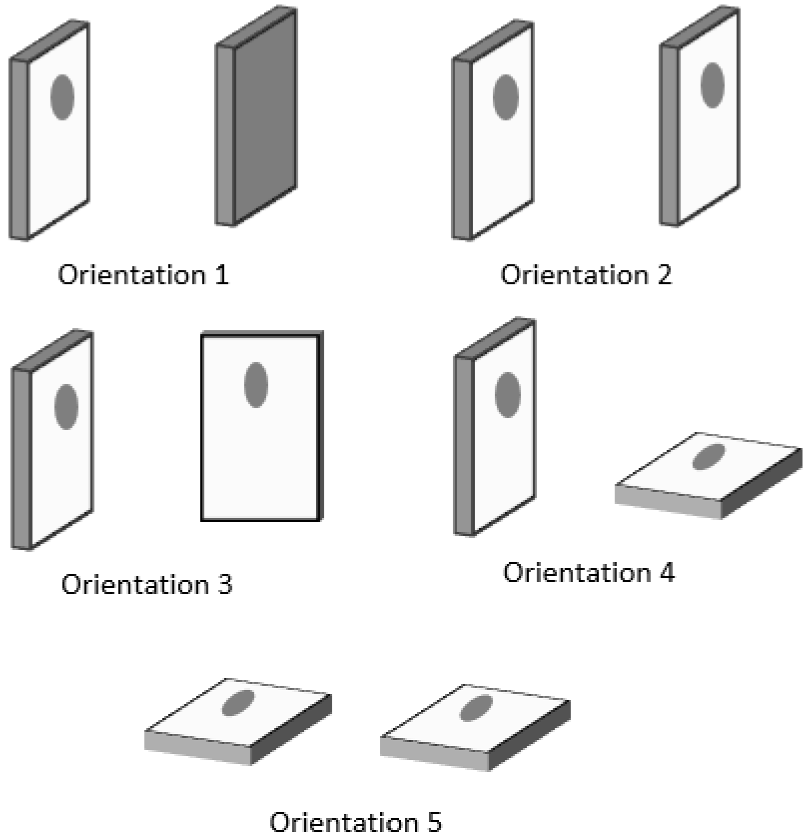

Figure 5. Reader (left) and tag (right) orientations for testing

B. Reader Altitude

Reader altitude is another factor that is important to consider especially in an indoor environment - a setup expected to have various physical obstructions that will affect the wireless communication between receiver and transmitter. RF signals require a football-shaped line-of-sight (LOS) path free of obstructions, otherwise known as the Fresnel Zone, to be able to transmit data optimally. Hence, it is essential to consider the height of the antenna from the ground as it may cause unwanted interference to the system. For the experimental setup, the readers will be positioned in varying altitudes, specifically 1m, 1.5m, and 2m from the ground, to determine which altitude best yields the most accurate RSSI data reading from the tags. The tags shall be put on a fixed height equivalent to the approximate height positioning of IDs on a person since in application, the tags are highly recommended to be placed on the ID of students and employees of the institution.

C. Determining of Optimal Antenna Orientation and Reader Altitude Setup

For the testing, the following variables should be noted. First, the three readers will all be placed in the same fixed height and fixed distance of 1m from the reader, but the angle and orientation will vary upon testing. And second, one reader will be placed on a fixed spot while its orientation and height will vary upon testing.

There will be a total of three different setups. The first one will have the reader in altitude 1m while the three tags will be deployed 1m from the reader, 1.2m from the ground, and at angles 0, 45, and 90 degrees with respect to the reader. The second one will essentially follow the same setup except the reader will be 1.5m from the ground. The third and last setup will have the reader placed 2m from the ground. For each of the three setups, the 5 antenna orientations will be tested correspondingly. Figure 6 shows how the testing setup will be conducted.

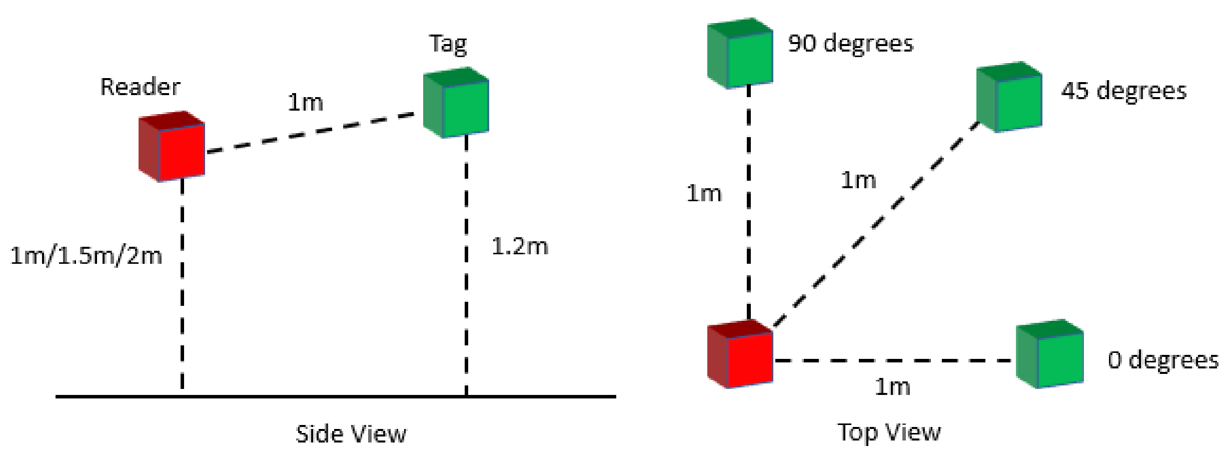

Figure 6. Setup to test optimal antenna orientation and reader altitude

The optimal setup will be determined by the RSS values with the least variation for different angles since the distance from reader to tag is fixed. To ensure that the measured RSS values are steady, data will be gathered in a time period of 5 minutes and then averaged. The standard deviation for the averaged RSS values at different angles will then be calculated. The setup with the lowest standard deviation will be considered the optimal conditions for the readers and tags, and consequently, be used for the proposed localization system.

Table 1. Proposed table for determining optimal antenna orientation and reader altitude

Orientation	Reader Altitude = 1m				Reader Altitude = 1.5m				Reader Altitude = 2m			
	0°	45°	90°	**σ**	0°	45°	90°	**σ**	0°	45°	90°	**σ**
1												
2												
3												
4												
5												

RSSI Conversion to Distance

The first step of processing tag information starts with the acquisition of RSSI information of the tag to the reader. Considering the multipath fading that occurs in an indoor RF environment, the experimental design will utilize the distance formula in (1) as a common fix to this issue.

$$d = 10^{\left(\frac{P_0 - F_m - P_r - 10*n*\log_{10}(f) + 30*n - 32.44}{10*n}\right)} \tag{1}$$

The distance equation expresses the transmitted power of a tag in terms of decibels represented by P_r in the equation. F_m refers to the fade margin, P_0 is the RSSI read at 0 meters, η is the path loss exponent, and f refers to the frequency. Aside from P_r, the variables in the given formula shall be calibrated to fit the testing zone of the system. Given these values, the distance d from tag to reader can then be obtained.

Trilateration

The trilateration algorithm used in data processing of distance readings will be adopted from [x][x] which assumes an isotropic electromagnetic power propagation in the setup producing a spherical curve for each reader. For a single reader, the distance between it and a tag is characterized using equation (2).

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \tag{2}$$

The distance information of the tag is represented as (x,y) while the fixed position of the reader in the test location is represented by (x_i,y_i). To create an estimation of the tag location, the distance readings in a reader are compared to other tags that have received the tag transmission. The location of the tag is described as the computed final location of a tag in the test location. It is obtained using the distance information from the readers in the narrowed quadrant composed of four readers to equation (3).

$$\begin{aligned} d_1 &= \sqrt{(x - x_1)^2 + (y - y_1)^2} \\ d_2 &= \sqrt{(x - x_2)^2 + (y - y_2)^2} \\ d_3 &= \sqrt{(x - x_3)^2 + (y - y_3)^2} \\ d_4 &= \sqrt{(x - x_4)^2 + (y - y_4)^2} \end{aligned} \tag{3}$$

By expanding the expression and regrouping the terms, the final expression for obtaining the location of a tag is seen in equation (4) and the equivalent of matrices A and b are shown on (5) and (6).

$$A \bullet (x\ y) = b \tag{4}$$

$$A = 2((x_2 - x_1)\ (y_2 - y_1)(x_3 - x_1)\ (y_3 - y_1)x_4 - x_1)\ (y_4 - y_1)\ ) \tag{5}$$

$$b = (d_1^2 - d_2^2 - [(x_1^2 - x_2^2) - (y_1^2 - y_2^2)]\ d_1^2 - d_3^2 - [(x_1^2 - x_3^2) - (y_1^2 - y_3^2)]\ d_1^2 - d_4^2 - [(x_1^2 - x_4^2) - (y_1^2 - y_4^2)]\ ) \tag{6}$$

Tag-to-tag Distance Measurement

With the computed location of the tags expressed as coordinates, the distance between two tags that are within the area can simply be computed using Pythagorean theorem since the map layout will only display the x and y coordinate of a tag. The z coordinate of the tag location will not be considered because the location of the tags along this axis will vary depending on how the tags are worn by the test participants. Moreover, a two-dimensional distance analysis is preferred over the three-dimensional distance of both tags since it can compute the proximity of both tags by using fewer variables than the latter method without omitting the necessary coordinates for the intended purpose. The equation for the distance between two tags is shown in (7).

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{7}$$

The distance between two tags is represented by d while coordinates (x_i, y_i) indicate the 2D tag coordinates.

Data Gathering Procedure

To analyze the accuracy and reliability of the proposed indoor localization system, the testing will be done in an enclosed rectangular area resembling a hallway with the size of 4.1m x 9.0m x 3.0m. The 4 readers and 3 tags will be positioned as described in the previous section about optimization and calibration.

The test environment will consist of chairs, walls, ceilings, and plastic tripods that will serve as holders of the 4 readers and 3 tags. The first type of test will focus on the accuracy of the system in obtaining the location coordinates of each of the unknown tags with movement. The path for the movement of each tag will be pre-determined in order to have a basis for the actual coordinates of movement to be compared to the calculated coordinates that will be shown on the GUI in a span of 5 minutes. The results will be evaluated using (8) wherein the location estimation error, *e*, is calculated as the linear distance between the unknown tag's actual coordinates (x_0, y_0) and the calculated coordinates (x, y).

$$e = \sqrt{(x - x_0)^2 + (y - y_0)^2} \tag{8}$$

Table 2. Proposed table for testing the accuracy of obtaining moving tag coordinates

Time (min)	Tag 1			Tag 2			Tag 3		
	Path Coordinates			Path Coordinates			Path Coordinates		
	Actual	Calculated	***e***	Actual	Calculated	***e***	Actual	Calculated	***e***
1									
2									
3									
4									
5									

Table 2 shows the proposed table for the data determining the accuracy of the system in locating moving tags in the area. Unlike the process of testing for optimization which only located static unknown tags, the data gathered from this procedure will establish how accurate the system is for the purpose of tracking people since, in actual setup, people will be moving instead of staying in one place.

The second part of testing will focus on verifying the reliability of the system to determine the distance between two tags accurately. For this setup, the three subject tags will be placed separately in the testing area and their coordinates and distance to one another will be manually measured and recorded. For each tag, their distance with respect to the other two tags shall be determined automatically by the system. The algorithm of the system will be able to automatically compute the distance between two tags once the coordinates of respective tags have been obtained. Once again, the calculated distance will be compared to the measured actual distance through the value of location estimation error.

Table 3. Proposed table for testing the accuracy of distance between two tags

Trial	Tag X	Tag Y				Tag Z			
			Distance				Distance		
	Coordinates	Coordinate	Actual	Computed	e	Coordinates	Actual	Computed	e
1									
2									
3									
4									
5									

Table 4 shows the proposed table for testing the accuracy of the algorithm of the system in calculating the distance between two tags. An integral part of the study is determining the proximity between tags to determine the feasibility of the system to be used for real-life applications that need to track the distance between two people; hence, it is essential to verify the feature of the system in providing high accuracy in automatically calculating the distance between two or more tags.

Statistical Treatment

For the statistical analysis of data, percentage of error and coefficient of variation will be utilized to evaluate the performance of the proposed indoor localization system for determining tag-to-tag distance in terms of accuracy and precision.

Percentage of error will be used to determine the closeness of the estimated result to the true value, which in this case pertains to the location coordinates of tags and the distance between two target tags. The equation for the percentage of error is shown in (9). A lower value of this percentage would indicate that there are less errors. The desirable percent of error is set to less than or equal to 10% so that the observed output may be considered as an acceptable value.

$$\%error = \left|\frac{Actual\ Value - Experimental\ Value}{Actual\ Value}\right|\ x\ 100\% \tag{9}$$

The tests will be conducted for 20 trials in order to evaluate the precision of the results. It is important to consider the precision of the observed outputs in order to establish that the results are consistent and not coincidental. The coefficient of variation, CV, will be computed following the equation in (10). The lower the value of CV means the precision of the values are greater. The acceptable CV is less than 10%.

$$CV(\%) = \left|\frac{Standard\ Deviation}{Mean}\right|\ x\ 100\% \tag{10}$$

Graphic User Interface (GUI)

The graphic user interface used to display the output of the system will be developed on MATLAB App Designer. Data used by the program will come from the XBee coordinator, namely the RSSI reading of the tag to a particular reader and its reference number. The computed coordinates from trilateration and distance will be done on MATLAB and is then displayed on the GUI. The interface will show where a particular detected tag is in the area as well as its distance to other tags. When the application is launched, the layout of the testing site is shown including the elements that comprises it. Map legends are placed below the interface for user reference and convenience. The red square represents the readers set on the 4 corners of the setup while the green circles are plots of the tag location. Physical obstructions such as chairs will also be displayed on the GUI as squares with white outline. The map is oriented to the interface in such a manner that allows mapping of coordinates on the 2D plane, with the x-axis at the bottom of the map and y-axis at the left.

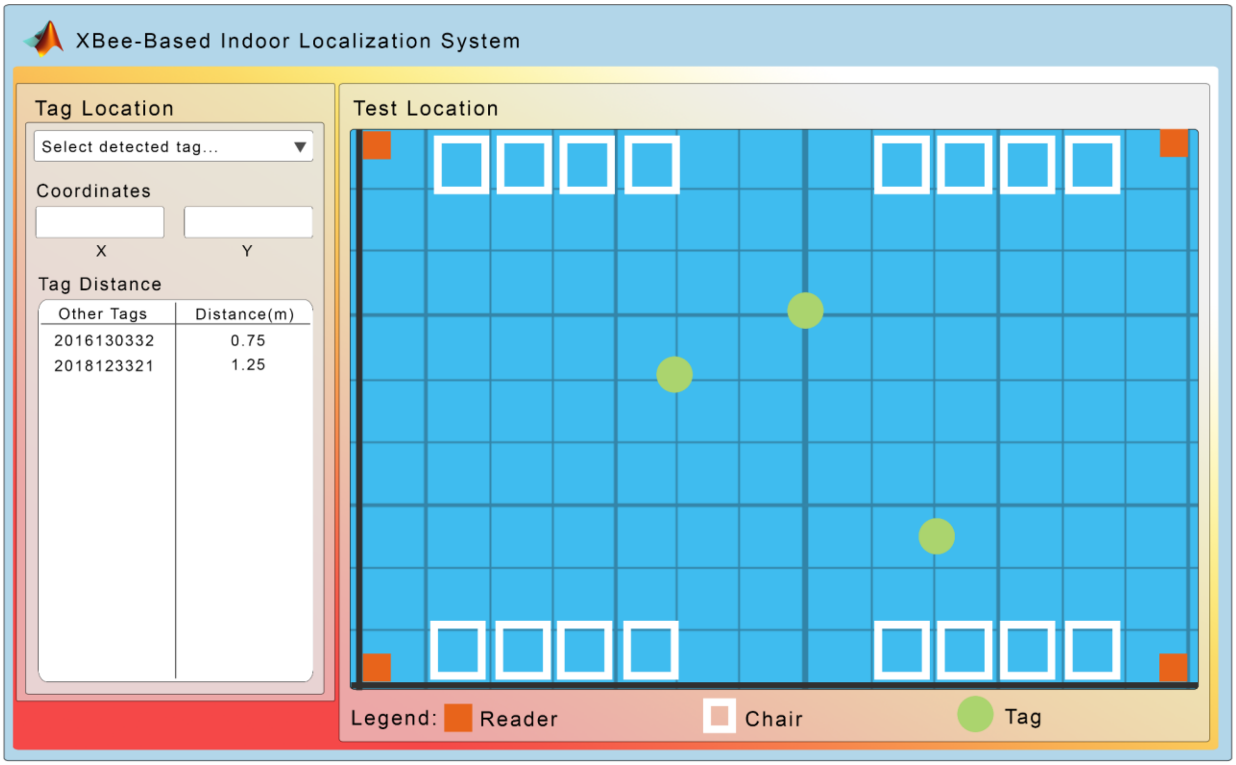

Figure 7. Main window for tracking tag location