Indoor Location Tracking through antennas and their Comparative Analysis

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Abstract: In the time of smart cities, there is a variety of applications where the localization of indoor environments is necessary, from monitoring and tracking in smart buildings to adjacency marketing and advertising in shopping complexes. The prosperity of these applications is based upon the progress of a cost-efficient and robust real-time system capable of precisely locating objects. In most outdoor localization systems, a global positioning system (GPS) is used because of its ease of implementation and efficiency up to five meters. But, due to the limited space-related to performing localization of indoor environments and interference found indoors, GPS is not a suitable option. Therefore, flawless and efficient locating of objects is a major challenge for indoor environments. Recent growth in the Internet of Things (IoT) along with recent wireless technologies can ease the problem. Small-size and cost-efficient IoT devices that use wireless protocols can provide an interesting solution. In this paper, we compare four wireless technologies for indoor localization: Wi-Fi (IEEE 802.11n-2009 at the 2.4 GHz band), Bluetooth low energy, Zigbee, and long-range wide-area network. The received signal strength indicator (RSSI) values from Wi-Fi modality were used and trilateration was performed for localization.

The system anticipates the location of the user inside a room and performs an action based on the location of the user in the bounds.

IndexTerms - RSSI, Location, Triangulation, ESP, Arduino, Path Loss Model

I. INTRODUCTION

By incorporating technological advancements into buildings, an important amount of information can be conveyed to those who occupy them in order to improve their experience. With the development of the Internet of Things (IoT), new less expensive and energy-efficient devices such as wearables and Bluetooth Low Energy (BLE) beacons have been made. These devices are able to communicate with the IoT to allow for smart buildings to possess a better amount of control that has never been achieved before. In IoT applications, it is essential that sensor data should not only be accessed, but the location of the sensor node inside of the building also needs to be known in order for the important information to be produced. If a centralized server is not aware of the device's locations, the data produced by those devices becomes insignificant and their limited resources are wasted. In order to improve competence and improve the experience of those who live in smart buildings, it is important that all devices are able to properly determine their position in real-time with very little knowledge of their surroundings. To determine a location, indoor localization is often executed. Indoor localization is a system that is used to locate objects or devices inside an environment where Global Positioning System (GPS) cannot be used. GPS is often used in outdoor localization systems as it is the simplest method. But, it consumes a large amount of energy and can be costly to implement for every node in a big network. Due to the dependency on Line-of-Sight (LoS) between GPS satellites and receivers, GPS can never be used indoors. Along with that, GPS comes with the maximum accuracy of up to five meters. This may be suitable for outdoors, where there is a large amount of space, but when we are inside homes, this is not advantageous due to limitations in the size of the environment. Hence, when executing localization indoors, a precision of less than one meter is important for a good localization system. Thus, other methods need to be employed in order to determine a device's position. Implementing an indoor localization system has many uses in a variety of areas. Employing indoor localization not only provides the added profit of safety and security but is also able to improve the efficiency of the working environment. For example when in hospitals, the indoor localization can be used for tracking patients. Doctors hence would be able to know exactly where a patient is situated inside the building without feeling the need to provide constant supervision. Another example can be in emergency situations, where first responders would be able to use indoor localization to help guide them quickly to anyone who is in distress without requiring to know the exact layout of that building. Because of the small size of a majority of

IoT devices, their hardware is often quite limited. They have low storage, minimal processing power, and very basic communication capabilities. Thus, any localization algorithms that are employed need to accommodate the abilities of these devices. In order for an indoor localization system to be successful, multiple targets will need to be tracked at once, while continuously updating when any targets are added, moved, or removed from the system. Unfortunately, indoor localization suffers from a larger number of problems that do not exist when performing localization outdoors. For example, there are many more obstacles indoors, including furniture, walls, and people, which can reflect the signals produced, thus increasing multipath effects. There are also a large number of wireless electronic devices that utilize WiFi and BLE which are using the medium and are transmitting information, which can produce noise that will affect the performance of the system. So far, a standard model for indoor localization has not been made due to obstacles, floor layouts, and reflections of signals that can occur. Some of the most common models that are used in localization systems are Angle of Arrival (AoA), Time of Arrival (ToA), Time Difference of Arrival (TDoA), and Received Signal Strength Indicator (RSSI). AoA systems adopt an array of antennae to determine the angle, from which the signal propagated. Triangulation is then used along with the geometric principle of angles of triangles to discover the position of the receiver. AoA techniques often require complex hardware and must be calibrated so that an accurate position can be obtained. ToA is one of the most accurate techniques that are available. Through the use of synchronized clocks, the signal propagation time between the transmitter and receiver can be calculated. ToA uses timestamps embedded in transmitted packets along with the received time to examine how far the packet had to travel to reach the destination. But, when using a ToA set up, devices in the network need synchronized clocks, which require additional hardware, thus increasing the cost of the system. TDoA is similar to ToA in that it needs devices to have synchronized clocks, but it uses the signal propagation time of multiple receivers to find the absolute signal propagation time. The distance can then be determined by the differences in the arrival time of the packet to the different receivers. RSSI is one of the most used and simplest methods for localization. The main reason for its popularity is that finding the RSSI requires no additional hardware and can be found on any device using almost any type of wireless communication technology. RSSI works by measuring the signal strength of packets on the receiver. It is usually used for finding the distance between the transmitter and the receiver because the signal strength decreases as the signal propagates outward from the transmitter. Since propagating signals are greatly affected by the noise in the environment, RSSI often leads to inaccurate values that can cause errors in the positioning system. In this paper, through extensive experimentation, Wi-Fi technology was chosen based on factors such as popularity, public availability, and use in the IoT. All tests were performed using a trilateration technique where the RSSI values were used in determining the approximate distances between the transmitting nodes and the receiver.

II. WIRELESS TECHNOLOGIES

When selecting a wireless technology, factors such as the transmission range, radio coverage, bitrate, as well as the battery life, and the power requirements should always be taken care of for a given application. In this section, previously mentioned IoT wireless communication technology can be used for indoor localization are discussed

IEEE 802.11N - WIFI

First released in 1997 using the IEEE 802.11 standard, WiFi has become one of the most commonly used wireless technologies. WiFi is mainly used in Wireless Local Area Networks (WLAN) through the use of the 2.4GHz or 5GHz frequency bands. In order to connect to a WLAN, a wireless access point is required. IoT devices make use of WiFi due to its wide availability in many areas. WiFi also has high security and privacy standards. However, WiFi networks are used for communication, so while connectivity and data rates are a high priority, localization is not their main concern. At the same time, the wide availability of WiFi can possess some challenges in the near future. As the number of devices that have access to the medium increases, it becomes overcrowded and interference problems may start to appear.

III. LOCALIZATION SYSTEM

3.1 Received Signal Strength Indicator

Received Signal Strength Indication (RSSI) is one of the most commonly used characteristics for indoor localization. It is based on measuring the power present in a signal sent from an access point to a client device or vice-versa. As radio waves attenuate according to the inverse-square law, the distance can be approximated based on the relationship between the transmitted and received signal strengths, as long as no other errors contribute to incorrect measurements. The combination of this information with a propagation model can help to determine the distance between the two devices. It can be assumed that as the number of available access points increases, a greater amount of information can be collected. Hence, the accuracy could be increased if relevant information is obtained. This, however, also works as a tradeoff. An increase in the number of access points would increase the interference between different signals. A key challenge in wireless localization systems is that the range measurements are often associated with errors. RSSI techniques are among the cheapest and easiest methods to implement, but they do not provide the best accuracy. Filtering is necessary to improve system accuracy using RSSI-based localization.

3.2 Triangulation

Trilateration is a model-based technique that is able to determine the 2D position of an object on the basis of the distance from three reference points along with the location of those points. To calculate using trilateration, three transmitting nodes placed in known locations along with a receiver are required. The transmitting nodes are set to continuously broadcast packets. Doing this allows the receiver to obtain any transmissions that take place over the medium and record the RSSI values of the packets. The RSSI values can then be converted to a length, which can provide the estimated distance between the nodes. To relate the determined RSSI values to a distance, the path loss model [21] was used, which can be seen here:

$$\mathrm{RSSI} = -10n\log_{10}(d) + C \qquad (1)$$

In this equation, n is the path loss exponent that varies depending on the environment, d is the distance between the transmitting and receiving devices, and C is a fixed constant that accounts for system losses. The path loss model was selected due to its ability to quickly determine a distance based on the RSSI values. Using the path loss model also allowed for environmental factors to be taken into account. Since RSSI values can fluctuate based on interference in the surrounding area, the path loss model can try to reduce some of the error that occurs, as the path loss exponent needs to be calculated for every environment before it can be used. However, due to the power level of the signal emitted from the transmitter not being precisely known, in many cases the path loss equation cannot be inverted and other methods are required to determine a distance [22], [23]. To determine a node's position using trilateration, a number of assumptions need to be made, one of which is that the location of all the transmitting nodes is known. To make calculations easier, the coordinate frame of the nodes was configured around a single node. This node was set up to be stationary at the origin and the other nodes were normalized with reference to that node. The general layout of a trilateration experiment can be seen in Fig. 1. In the setup, node A was set to be stationary at the origin (0,0). Node B was placed along the positive horizontal axis with respect to node A, giving a coordinate of (p,0). Node C can then be placed with respect to nodes A and B in the positive horizontal and vertical axis, producing a coordinate of (q,r). Node D is the receiver, placed at the known coordinates (x,y). The calculated distances to the receiver from nodes A, B, and C are referred to as e, f, and g respectively, which can be determined using the path loss model in Eq. (1). Once the positions of the transmitters and the distances to the receiver are determined, a new set of equations can be created. Using the general formula of a circle, three equations Eq. 2, Eq. 3 and Eq. 4, were determined corresponding to nodes A, B and C respectively. By solving this set of equations and finding the overlapping point, the position of the receiver can be found.

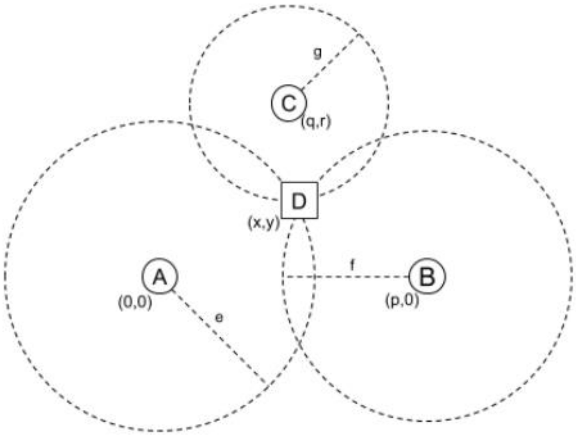

Figure 1 General Setup for trialation

$$e^2 = x^2 + y^2 \qquad (2)$$
$$f^2 = (x - p)^2 + y^2 \qquad (3)$$
$$g^2 = (x - q)^2 + (y - r)^2 \qquad (4)$$

In these three equations, there are two unknowns that can be determined-x and y-which correspond to the estimated location of the receiver, and which should satisfy all three equations. By using simple reduction techniques, a solution can be determined. By subtracting Eq. 2 from Eq. 3, the variable y can be eliminated. The remaining parameters are those of the single unknown variable x, the distance between nodes A and B, and the distances between the transmitting nodes A and B with the receiver node D. After some rearranging, the final result can be seen

$$x = (e^2 - f^2 + p^2)/2p \qquad (5)$$

In order to produce a single solution for the y position of the receiver node, another subtraction can be performed, this time using Eq. 2 and Eq. 4. After solving and rearranging, the solution for y can be seen in Eq. 6. This equation is entirely in terms of known parameters which can be substituted in to solve for a value.

$$y = (e^2 - g^2 + q^2 + r^2)/(2r) - (qx)/r \qquad (6)$$

3.3 ACCURACY

To determine which wireless communication technology produces the most accurate results, the error between the actual and the estimated position can be found using the Mean Squared Error (MSE). The MSE is a calculation of the difference between two points to find the error. The formula used can be seen here:

$$\text{Error} = \text{sqrt}\left((x_{calc} - x_{real})^{2} + (y_{calc} - y_{real})^{2} \right) \quad (7)$$

In this equation, x_{calc} and y_{calc} is the calculated position, and x_{real} and y_{real} is the actual position of the receiver. Once the errors for all the tests performed are determined, an average can be taken that can then be compared to the other wireless communication technologies to determine which produced the most accurate results. In addition to accuracy, the power consumption of wireless technologies was also determined.

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IV. Experimentation Apparatus

For this experiment, four ESP8266 were used. The devices contained an onboard 2.4GHz WiFi chip antenna. Hence, a simple WLAN could be created using said controllers by programming them to transmit and receive signals. Three nodes were configured to be the transmitters and one node was set to be the receiver. The receiver node was set up as an access point, where it would broadcast a signal that the other nodes could use to connect to the WLAN and provide communication capabilities between the devices. Each of the transmitting nodes continuously polled their WiFi antenna, scanning for any available signals along with their measured RSSI values. The RSSI values would then be transmitted to the receiver along with the identity of the node that was sending the data. All received data would then be displayed on the terminal of the device. To record the measured RSSI values, a computer was connected to the network of the receiving node.

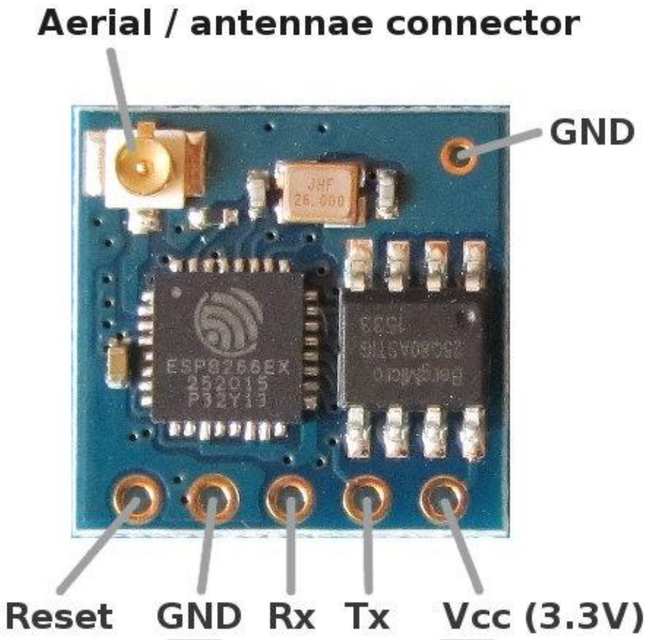

Figure 2: ESP8266 module

Figure 3: Arduino Mega

V. Path Loss Model

Before any experiment could be performed, the path loss models in the environments for each of the different wireless communication technologies needed to be determined. For each of the systems designed, a transmitter is placed at the start end marking it as 0 and thereafter the receiver was taken from 10 cm to 300 cm with steps of 10 cm and measuring

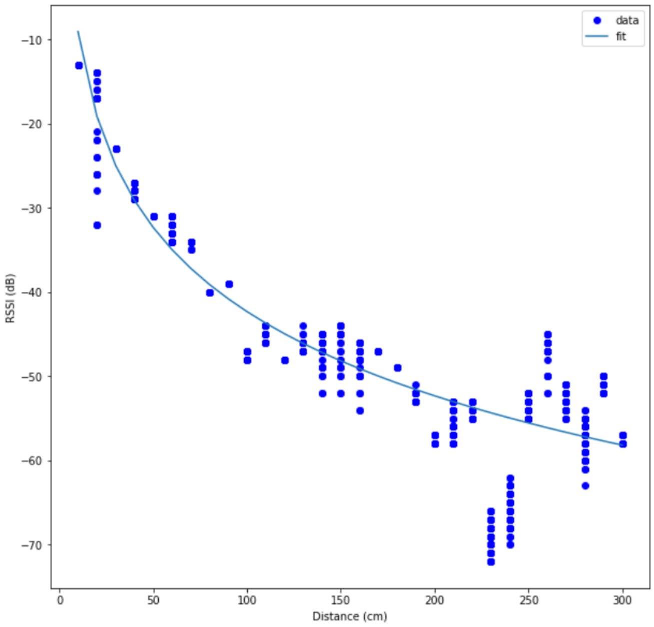

Figure 4. Curve Fitting For the path loss of Dipole Antenna

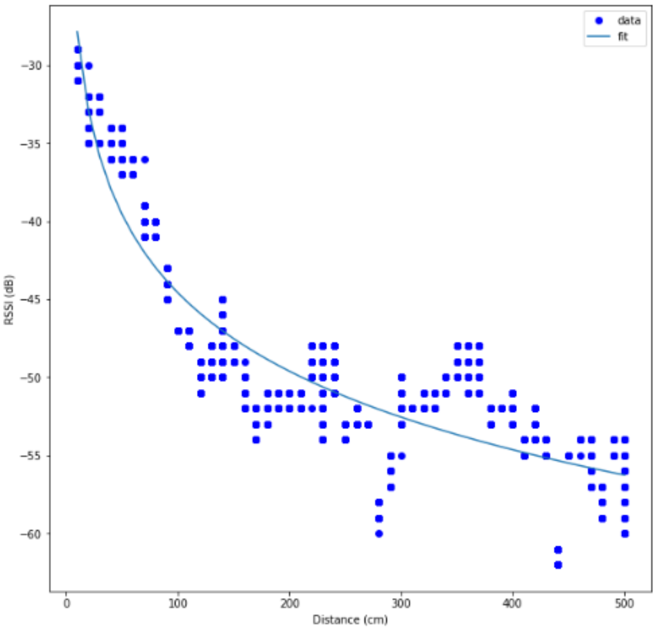

Figure 5. Curve Fitting For the path loss of ESP On-Chip Antenna

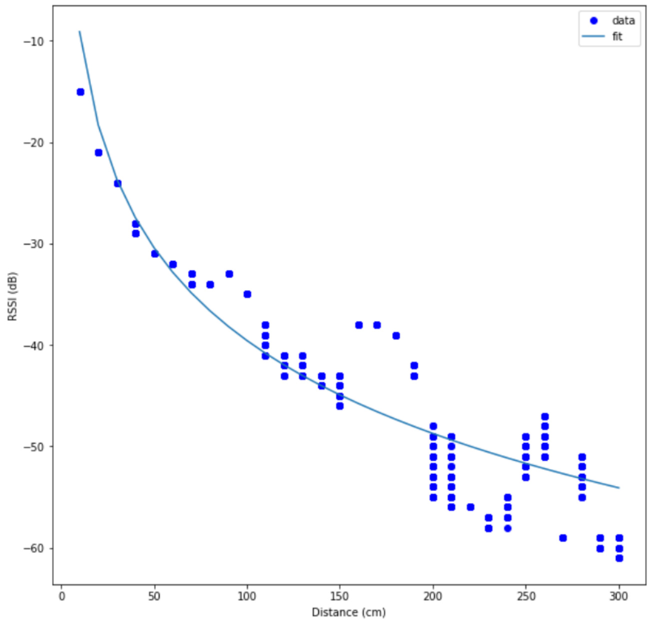

Figure 6. Curve Fitting For the path loss of single-strand wire Antenna

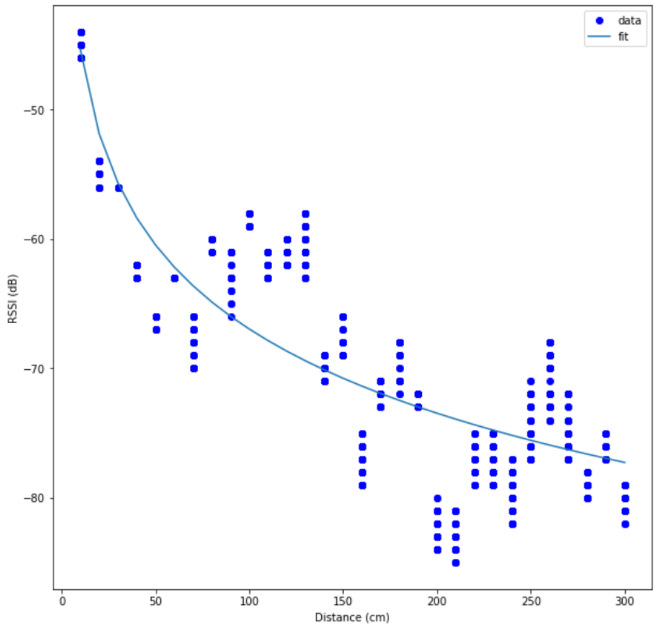

Figure 7. Curve Fitting For the path loss of Solenoidal Antenna

RSSI at every step. RSSI readings of these 30 points are then fed to a logarithmic curve fitting module in python which is used to estimate a model based on Eq.(1).
The reading of the model was taken in a typical home environment with a normal noise interface that must be tackled.

The above-described process is performed for a different type of antennas to determine which type can be used to effectively generate the model to minimize the error caused by the surrounding noise.

To determine which antenna is best suited for determining the path loss model, distance verses RSSI data was collected for each antenna and model was generated for each one of them.

The curve fitting for the path loss in the home environment for the antennas is shown in Fig. (4-7)

Table 1. Parameters used in converting RSSI to distance using the path loss model

Parameters	Dipole model	Spiral Model	Esp Model	Single Strand Model
n	3.32345255	2.16075028	1.67176951	3.04532983
C	24.14602405	-23.74901965	-11.14511358	21.33887804

Table 1 shows the values of the parameters derived for different antennas. These models show that the variance in the values starts to deviate from the model as the distance between the transmitting node and the receiving node increases. Furthermore, at some points, the value fluctuates largely whereas at other places it remains constant. This fluctuation might be a result of surrounding noise or human interaction with the receiver. Apart from it the sign could itself cause interface when taking multiple paths to reach the node thereby interface with itself which can either be constructive or destructive.

Now, these derived models are implemented and tested for actual conversion.

This time instead of recording the RSSI value for each point, the derived models were used to calculate the distance between the node. So, the calculated and actual data reading were recorded and plotted to determine which antenna suites best for purpose.

The Esp with the on-chip antenna was removed from the selection as later it was determined that its gain is not the same in all directions.

Them the average of the calculated distance versus actual distance was calculated for analysis.

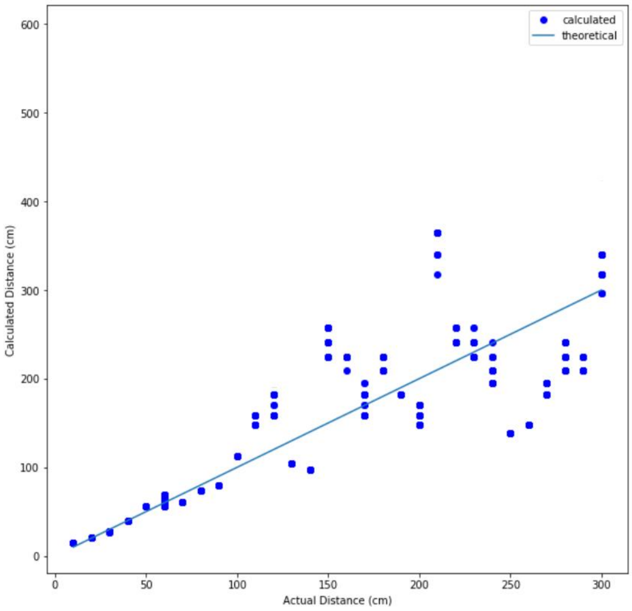

Figure 8. Calculated Distance vs Actual Distance for dipole antenna

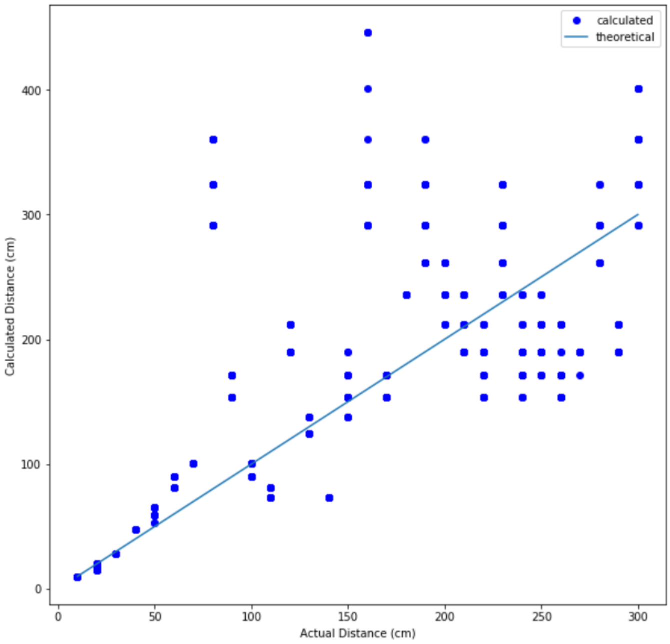

Figure 9. Calculated Distance vs Actual Distance for Spiral antenna

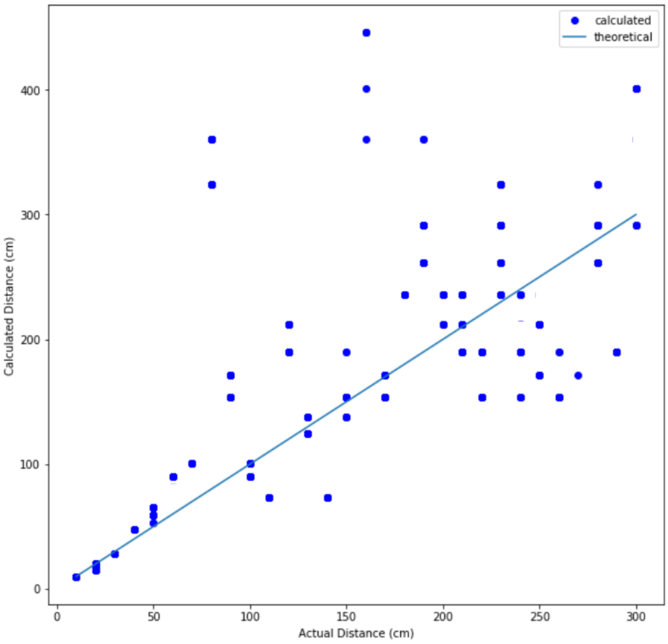

Figure 10. Calculated Distance vs Actual Distance for ESP Antenna

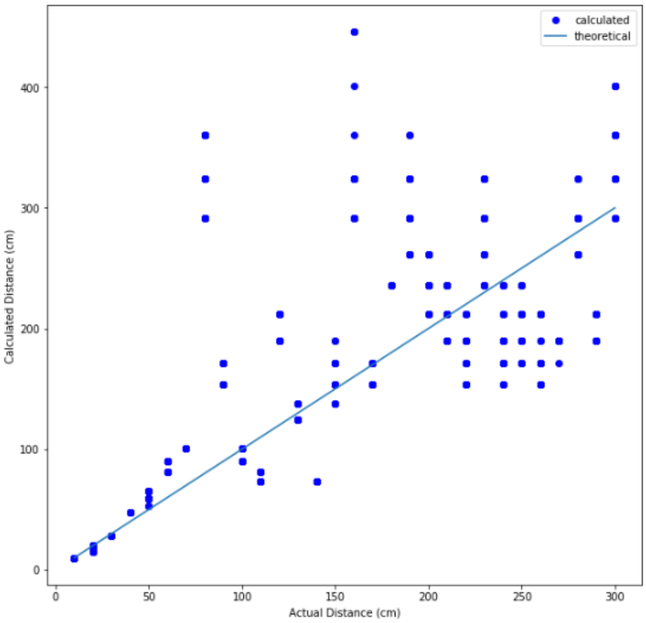

Figure 11. Calculated Distance vs Actual Distance for Single Strand Antenna

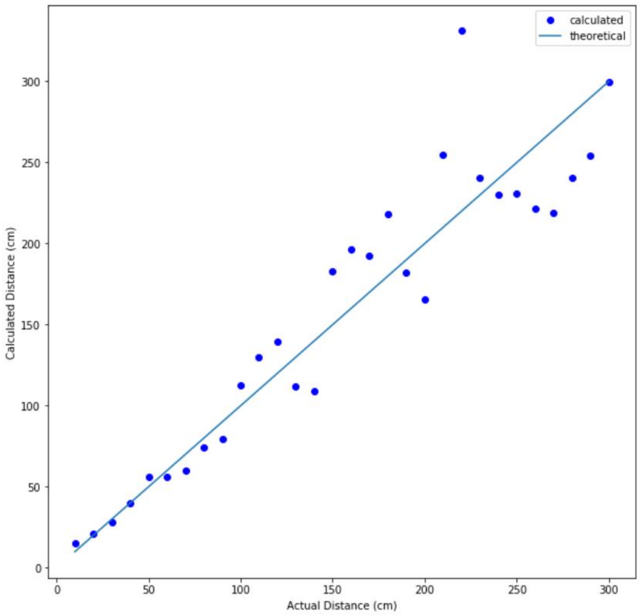

Figure 12. Calculated Average Distance vs Actual Distance for Dipole Antenna

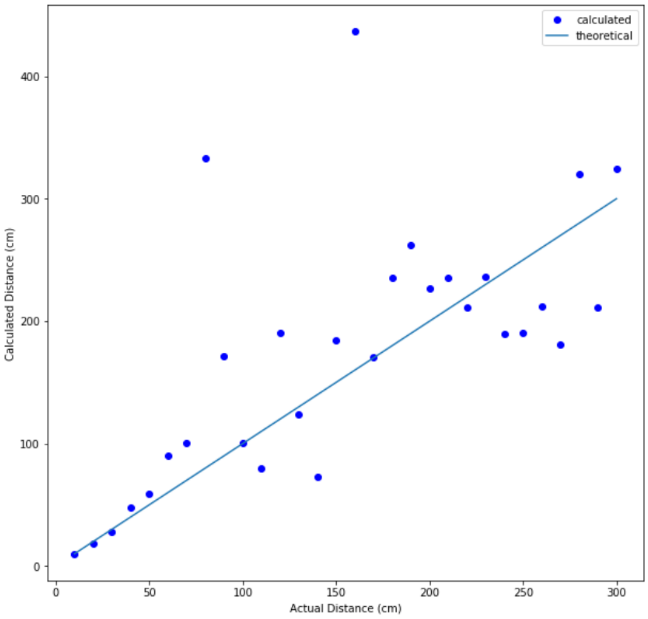

Figure 13. Calculated Average of Distance vs Actual Distance for Spiral Antenna

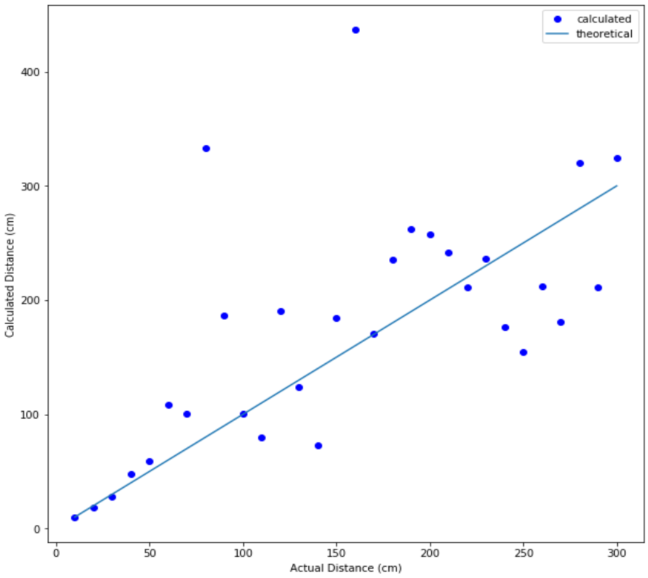

Figure 14. Calculated Average of Distance vs Actual Distance for ESP Antenna

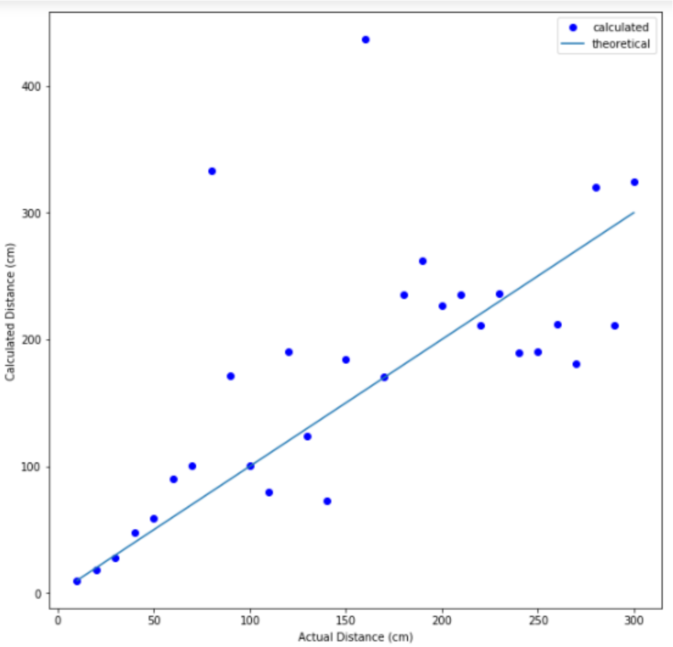

Figure 15. Calculated Average of Distance vs Actual Distance for Single Strand Antenna

After comparing these diagrams Dipole antenna was selected to be used for this project.

VI. EXPERIMENTAL PROCESS

After the appropriate antenna was selected, two more receiver nodes were added to the system. Arduino mega acts as a central place for processing the location. Esp 05 was used as a transmitter and receiver with a dipole antenna. These nodes communicate with Arduino mega over the serial interface and transfer their corresponding distance from the transmitter to Arduino mega. Then the equations (5) and (6) are used to determine the calculated location of the transmitter node.

The receiver nodes were placed along the axes as shown in Figure 16. This configuration is chosen to an attempt to reduce location parameters for the nodes thus decreasing the computational process require for determining the location.

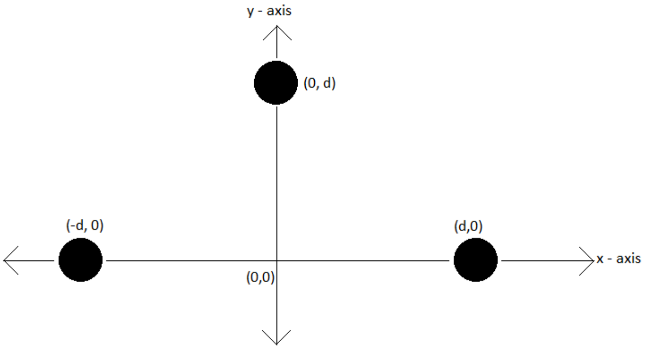

Figure 16. Receiver Nodes Configuration

After placing the receiver nodes on the position, the transmitter node placed at various coordinates for the system to sense the RSSI and determine location using the selected Model.

VII. RESULT

The proposed system is using an Arduino Mega with 3 ESP8266 connected in perpendicular arrangement to detect the position and direction of a transmitter node from the centre point where the setup is kept. The delay in receiving the position after the ESP boots up and connects to receiving phone is 100ms. The device for which the direction needs to be identified is acting as a beacon for which the direction can be calculated based on the RSSI value received from the WiFi signals of the ESP8266.

The experimental results revealed useful insights. In terms of accuracy, WiFi produced estimates that were closest to the actual receiver position, deviating by 0.664 meters. However, WiFi was also found to use a large amount of power which would not be suitable for use in a system that requires batteries to function.

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