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Indoor Location Detection of User using Radio Frequency of WiFi

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Abstract—In the era of smart cities, there are a plethora of applications where the localization of indoor environments is important, from monitoring and tracking in smart buildings to proximity marketing and advertising in shopping malls. The success of these applications is based on the development of a cost efficient and robust real-time system capable of accurately localizing objects. In most outdoor localization systems, global positioning system (GPS) is used due to its ease of implementation and accuracy up to five meters. However, due to the limited space that comes with performing localization of indoor environments and the large number of obstacles found indoors, GPS is not a suitable option. Hence, accurately and efficiently locating objects is a major challenge in indoor environments. Recent advancements in the Internet of Things (IoT) along with novel wireless technologies can alleviate the problem. Small-size and cost-efficient IoT devices which use wireless protocols can provide an attractive 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 predicts the location of the user within a room, and performs action based on the location of the user in the premises..

I. INTRODUCTION (HEADING 1)

By integrating technological advancements into buildings, a significant amount of information can be delivered to those who inhabit them in order to improve their experience. Through the development of the Internet of Things (IoT), new low cost and energy efficient devices such as wearables and Bluetooth Low Energy (BLE) beacons have been developed. These devices are capable of communicating with the IoT to allow for smart buildings to poses a greater amount of control that could never have been achieved before [1], [2]. In IoT applications, it is imperative that sensor data should not only be obtained, the location of the sensor node inside of the building also needs to be known in order for the information produced to be useful [3]–[5]. If a centralized server is unaware of the device's positions, the information produced by those device becomes irrelevant and their limited resources are wasted. In order to increase efficiency and improve the experience of those who reside in smart buildings, it is imperative that all devices are able to efficiently determine their location in real-time with minimal knowledge of their surroundings. To determine a position, indoor localization is often performed. 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. However, it consumes a large amount of energy and can be expensive to implement for every node in a large network [6]. Due to a dependency on Line-of-Sight (LoS) between GPS satellites and receivers, GPS cannot be used indoors. Additionally, GPS only provides a maximum accuracy up to five meters [7]. This may be suitable outdoors, where there is plenty of space, but indoors this is not feasible due to limitations in the size of the environment. Therefore, when performing localization indoors, an accuracy of less than one meter is required for a proper localization system. Hence, other methods need to be used in order to determine a device's location [8]–[10].

Designing an indoor localization system has many uses in a variety of areas [11], [12]. Using indoor localization not only provides the added benefit of safety and security, but is also able to improve efficiency in the working environment. One example is in hospitals, where indoor localization can be used for tracking patients [13]. Doctors would be able to know exactly where a patient is located inside the building without needing to provide constant supervision. Another example is in emergency situations, where first responders could use indoor localization to help quickly guide them to anyone who is in distress without needing to know the exact layout of the building [14]. Due to the small size of a majority of IoT devices, their hardware is often quite limited. They contain low storage, minimal processing power, and very basic communication capabilities. Therefore, any localization algorithms that are used need to accommodate to the capabilities 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..

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Unfortunately, indoor localization suffers from a larger number of complications that are not present when performing localization outdoors. For instance, there are many more obstacles indoors, including furniture, walls, and people, which can reflect the signals produced, increasing multipath effects [7], [8], [15]. There are also a large number of wireless electronic devices utilizing WiFi and BLE that are accessing the medium and transmitting information, which could produce noise that would affect the performance of the system.

So far, a standard model for indoor localization has not been developed due to obstacles, floor layouts, and reflections of signals that can occur [8]. 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 use an array of antennae to determine the angle, from which the signal propagated [8], [16], [17]. Triangulation is then used along with the geometric principle of angles of triangles to determine the position of the receiver. AoA techniques often require complex hardware and must be calibrated in order for an accurate position to be obtained. ToA is one of the most accurate techniques available. Through the use of synchronized clocks, the signal propagation time between the transmitter and receiver can be determined [16], [20]. ToA uses timestamps embedded in transmitted packets along with the received time to determine how far the packet had to travel to reach the destination. However, when using a ToA set up, devices in the network need synchronized clocks, which requires additional hardware, thus increasing the cost of the system. TDoA is similar to ToA in that it requires devices to have synchronized clocks, but it uses the signal propagation time to multiple receivers to find the absolute signal propagation time [17]. The distance can then be calculated by the differences in arrival time of the packet to the different receivers. RSSI is one of the most popular and simplest methods for localization [18]–[19]. The main reason for its popularity is that finding the RSSI requires no additional hardware and can be found on any device utilizing almost any type of wireless communication technology. RSSI works by measuring the signal strength of packets on the receiver. It is often used for finding the distance between the transmitter and the receiver, since the signal strength decreases as the signal propagates outward from the transmitter. Since propagating signals are greatly susceptible to noise in the environment, RSSI often leads to inaccurate values that can cause errors in the positioning system.

In this paper, through extensive experimentation, the 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 utilized 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 considered for a given application. In this section, previously mentioned IoT wireless communication technology that 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 [20]. 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 deployed for communication, so while connectivity and data rate are a high priority, localization is not their main concern. At the same time, the wide availability of WiFi can pose some challenges in the near future. As the number of the devices that have access to the medium increases, it becomes overcrowded and interference problems may arise.

III. Localisation System

A. 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.

B. 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:

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

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 (2), (3), and (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.

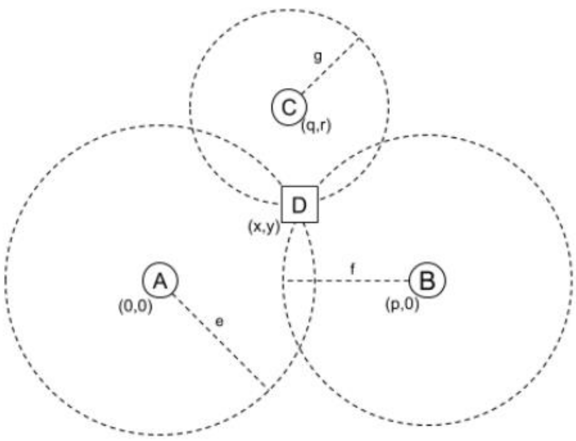

Figure 1 General Setup for trialation

$$e^2 = x^2 + y^2 \qquad (2)$$

$$f^2 = (x - p)^2 + y^2 \qquad (3)$$

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

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 (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 Eqs. (2) and (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.

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

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 antennas 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 a router, 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.

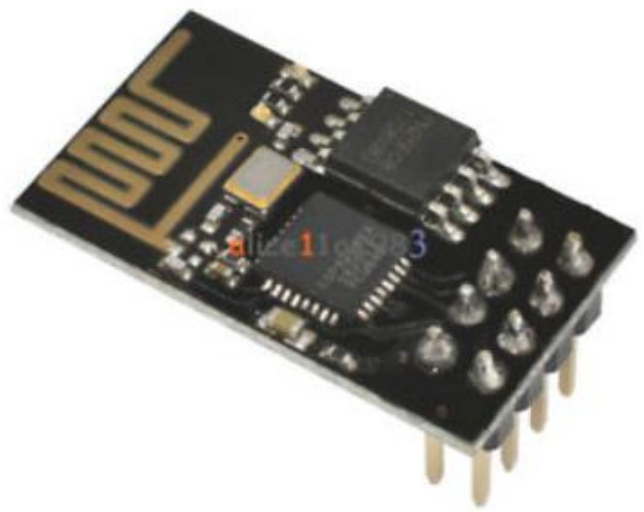

Figure 2 : ESP8266 module

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 single transmitter and receiver were placed over a range of fixed positions and the corresponding RSSI values were recorded. In order to create these models, the RSSI over a range of distances from the transmitter needed to be measured in the environment to determine how the signal strength decreases. It was determined that points over a range of distances would create the best fit, therefore, distances were selected between 0 to 5 meters. In total eighteen points were taken. Nine points were taken between 0 and 1 meter, once every 0.1 meters.

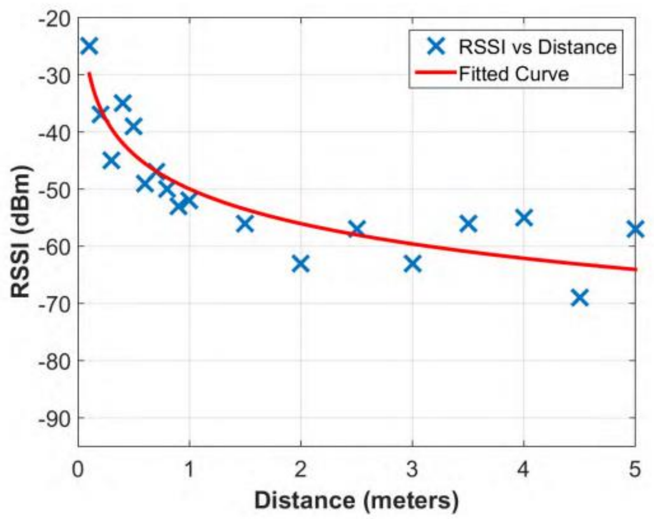

Figure 4. Curve Fitting For the path loss

V. RESULT

The proposed system is using an Arduino Mega with 3 ESP8266 connected at 120 Degree Circular arrangement to detect the position and direction of a mobile device 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 having an Application installed which calculates the direction based on the RSSI value received from the WiFi signals of the ESP8266.

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