Indoor Position Tracking based on Arduino, Xbee and Ethernet shield

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Contents

1 Introduction

The idea of this project comes from Marauder's Map of Harry Potter. The objective is to build a positioning system based on communication technologies that could be used to follow the user in the building or indoor environment. One of main key of this project is we can build a communication system of wearable objects. These objects will communicate, exchange the data and from their data, we would perform an analysis later to get some useful information. The other idea needed to consider was the user's privacy.The system doesn't detect users himself, but it detects an object worn by this user. It means sometime, the user don't want to be tracked hence the user can interact with this object to manage its privacy and change the object's setting follow his/her needs. We built this system with the combination of Arduino, Xbee and Ethernet shield as main seed. User will bring a broadcaster device and move around the building that is placed with a lot of receiver devices. Through calculation of distance based on the signal strength we got from each receivers, we can determine where the user stay in the building.

This report is organized as follow: First, we introduce the literature review about the context, the limitation of position tracking technologies, our objective, existing approaches and some conclusions in Section 2. We go into more detail about our objective, short presentation about our devices in Section 3. The experiment setup and the results can be found in Section 4. After the experiment, we deduce the conclusions in Section 5 and some further work in Section 6.

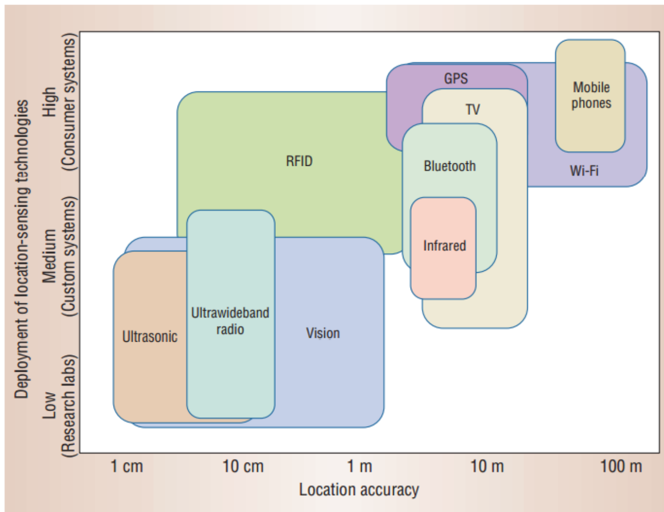
2 Literature Review

2.1 Context

There are many different kinds of positioning technologies such as Global Positioning System (GPS), cellular phone tracking system, WLAN positioning system and RFID Positioning System. All these technologies have different coverage, applications, accessories and limitations (Hazas, M. et al. [1]). We can see the comparison of Mike Hazas between each technologies from the Figure 1 on page 4: This Figure is a prediction for the trend in position tracking system in the next few years right after 2004 and the location accuracy between each systems. As we may see, some technologies just could be used only in laboratory like Ultrasound, Vision...due to its hard of deployment. On the other hand, some systems were very promising in the development for next few years like WLAN, GPS or mobile phone have lack of accuracy location in indoor environment like building or smaller area like office room, hall...

In this context of our report, we want to find a balance solution between the cost of deployment, the accuracy of position tracking and easy to step in the industry for the future to track, survey continuously and evaluate user's privacy concerns in a small, indoor area.

Figure 1: Location-sensing technologies. Each box's horizontal span shows the range of accuracies the technology covers; the bottom boundary represents current deployment, while the top boundary shows predicted deployment over the next several years.[1]



2.2 Limitation of position tracking technologies

Global Positioning System (GPS):

- Accuracy: There is a lot of things can affect the accuracy of GPS signal like it can be refracted by the dispersive ionosphere or the impact of solar maximum and storm activities lead to inaccurate positioning mentioned by Shoke et al [2]

- Reception: The GPS signal can not penetrate through wall, water, soils. Even though in the urban area, the signal still can be obstructed for a long period of time or even continuously unavailable.We can not do surveying or tracking inside tunnels, or building...

- Integrity: GPS receiver/processor must get at least 4 signals from 4 GPS satellites to calculate base on a range measurement to find an appropriate position. Any wrong position of GPS satellites or wrong measurement can lead to inaccurate position mentioned by Alfred et al [3]

We can see GPS is not suitable for indoor area so we need to find a way to take position tracking inside buildings, tunnels or underground environments to detect people, objects to find or to rescue in case of catastrophe.

The infrared-based system like Active Badge System of Roy Want et al [4] was first installed in Cambridge University UK was very good system when it could find and forward call exactly to where the user was. Although the price of active badges and networked sensors are cheap, the cables connecting sensors raise the cost of the Active Badge system. And this system had problem with privacy issue and they still needed to improve it to let users handle their privacy themselves like they could decide when and where the system couldn't track them, who or what could access to the data location of each user...And currently, this project had been closed down. No commercial product of this system is available. Another infrared system is Firefly, and the cost of a Firefly system with a camera array, one tag controller and 32 tags is 27500$, this price was very expensive to deploy the system in small area. Another problem with this system is the user comfortable, although the tag and battery is light weight, wear it all the time was not a good experience for user [5].

Beside the infrared-based system, we may hear about the ultrasound system, based on the idea of bat use ultrasound to find direction when fly. The system can be tracked with an accuracy of about 3 cm for 95% of the measurements but the performance of this technology is influenced by the reflection and obstacles between tags and receivers and deploy a large number of sensor is a time-consuming task.

In the other hand, the WLAN-based system have good accuracy location with range from several meters to 10 meters, the problem was this kind of system usually required more fixed base station for coverage and because of complex indoor environments consisting of various influenced sources and when the number of people in the building increase significantly, the performance of the positioning systems are not very accurate.

The Bluetooth-based system can reuse the other Bluetooth device, that is very effective and save the cost. But the accuracy is just around 2 meters to 3 meters and delay about 20 seconds [5]

In case of RFID system, we still needed to use a lot of passive RFID tag or some expensive RFID readers to detect people in space or object tracking...

We may think about using infared-based system, WLAN or Bluetooth-based system or in this report, we want to mention about using signal that is similar with RFID system to detect object in these areas.

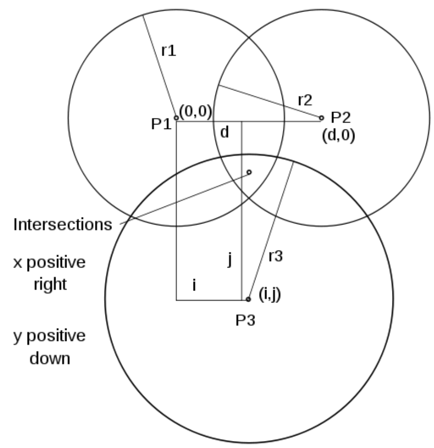
2.3 Objective

We define an alternative way to detect people, object in small or underground area through the radio signal. We know that there is the relation between signal strength and distance. So if we know the strength of signal, we can recalculate to know the distance. And for further thought, if we can know at least 3 distances to the object or people that we want to know their position, we can apply the trilateration (Figure 2) method to determine where they are.

2.4 Existing Approaches

Jeffrey H. et al. used the SpotOn tag to define a location sensed system in three dimensional based on radio signal strength analysis [6]. SpotON tags are

Figure 2: The plane z = 0, showing the three sphere centers, P1, P2, and P3; their x,y-coordinates; and the three sphere radii, r1, r2, and r3. The two intersections of the three sphere surfaces are directly in front and directly behind the point designated intersections in the z = 0 plane(From Wikipedia)



custom devices that operate standalone or potentially as a plug in card enabling larger devices to take advantage of location-sensing technology.

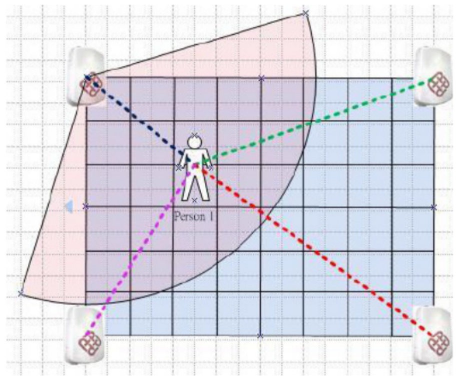
Guenther R. et al used the active RFID tag trilateration for indoor positioning [7]. RFID tag first is used for identification but can be used also for position determination. A RFID system consists of a tag, a reader and an antenna.There are various types of tags; i.e., passive, active and semipassive tags. Passive RFID tags do not have their own power supply and the read range is less than for active tags, i.e., in the range of about a few mm up to several meters. Active RFID tags, on the other hand, must have a power source, and may have longer ranges and larger memories than passive tags. And they choose to use the active tag to deploy and convert the signal strength to the distance to deduce the position based on trilateration.

In the other hand, S.L. Ting et al used passive RFID tag for indoor positioning [8] to offer a low cost solution for locating large number of items as we can see in Figure 3. S.L. Ting et al also proved that accuracy of the RFID Positioning System is 93% which is a high accuracy rate and the cost is cheap.The experimental results conclude that the passive positioning solution is feasible based on the measurement of RSSI and Euclidean distance. The low overall cost of implementing the positioning system at small warehouse makes it easy to be accepted by the industry.

On the contrary, instead of using at least 4 RFID readers like S.L. Ting et al to determine an object that attached with a passive RFID tag, Ali M. et al used 1 RFID reader and a number of passive radio tags to place in a whole building, they applied this solution to track the project construction status of a building.

Philipp V. et al [9] also did a comparison between 3 indoor positioning

Figure 3: Example of an object in an RFID covered zone [8]



tracking technologies: WLAN, Bluetooth-based and RFID passive tag. They performed an experiments that used all of 3 methods and they got the results as Figure 4. We may see the RFID measurement gave a good accuracy result, Bluetooth-based measurement's results was not much different but the WLAN was lower than both of the previous measurements.

Figure 4: Mean absolute positioning errors (in meters) for the three technologies. [9]

Method	Mean ± Std.dev.	Median	90th percentile
RFID	0.432 ± 0.095	0.435	0.527
Bluetooth	0.494 ± 0.149	0.474	0.678
WLAN	3.315 ± 0.738	3.545	4.274

2.5 Conclusions

There are different approaches to solve the indoor positioning problem like RFID system, infared-based system, Bluetooth or WLAN-based system. But we may consider RFID is the promising solution until now based on several criteria like accuracy, cost... S.L. Ting et al mentioned that their solution was easy to be accepted because of it low cost of implementing the system but actually, the price of a RFID reader varies from $500 to $ 2000 depends on the features in the device [1]. This price is still high and expensive if we want to use a RFID

[1] http://www.rfidjournal.com/faq/show?86

position tracking system in small area. We need to find a better solution that can adapt our needs and our financial situation.

3 Proposal

3.1 Project overview

In this concept of this report, we want to implement based on the idea of RFID-based system to position tracking but neither use the RFID reader nor the passive RFID tags. However, we want a cheaper method with an approximate accuracy. So we used an alternative way to broadcast the signal and receive the signal at the same time to calculate the position in fixed space. Consequently, we thought of using Arduino Uno board with Xbee shield and Ethernet shield. The user would bring a broadcaster and go around the building, from the data that we received from the receivers, we could track the position of the user. We could also build a tracking path, from this path, we could know about user's habit like how long he/she stay at his room to work?

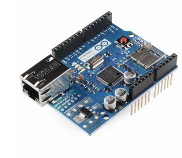
3.2 Arduino Uno Specification

The Arduino Uno (Figure 5c)is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. We use mainly this board to run our programs.

3.3 Xbee S1 or XBee 802.15.4 modules

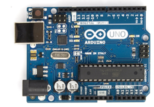
The XBee and XBee-PRO OEM RF Modules were engineered to meet IEEE 802.15.4 standards and support the unique needs of low-cost, low-power wireless sensor networks. The modules require minimal power and provide reliable delivery of data between devices. The modules operate within the ISM 2.4 GHz frequency band and are pin-for-pin compatible with each other.

In this report, we use mainly the normal Xbee S1 (Figure 5b), here is some features:



(a) Ethernet Shield

(b) Xbee S1



(c) Arduino Uno Revision 3

Figure 5: Group of requirement devices

Performance	Xbee
Indoor/Urban Range	up to 100 ft. (30 m)
Outdoor RF line-of-sight Range	up to 300 ft. (100 m)
Transmit Power Output (software selectable)	1mW (0 dBm)
RF Data Rate	250,000 bps
Serial Interface Data Rate(software selectable)	1200 - 115200 bps (non-standard baud rates also supported)
Receiver Sensitivity	-92 dBm (1% packet error rate)
Power requirements	Xbee
Supply Voltage	2.8 – 3.4 V
Transmit Current (typical)	45mA (@ 3.3 V)
Idle or Receive Current (typical)	50mA (@ 3.3 V)

3.4 Ethernet shield

The Arduino Ethernet shield allows an Arduino board to connect to the internet using the Ethernet library and to read and write an SD card using the SD library.

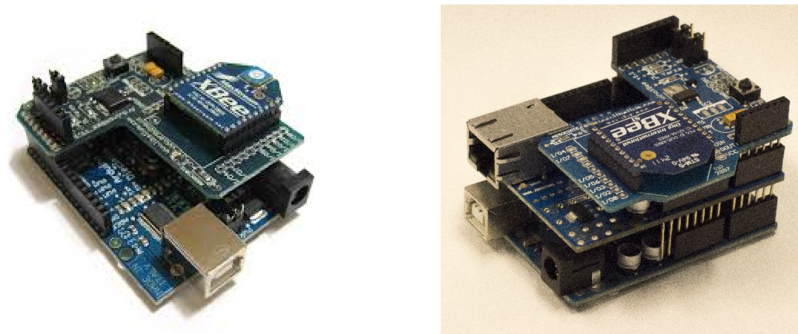
In Section 4, we indicated an unique MAC address and IP for every Ethernet shield that we used (Figure 5a)

We used Xbee to broadcast the signal and used another Xbee module to receive that signal. We make two groups of boards:

- Broadcaster: Arduino Uno board and Xbee Shield to broadcast the signal every 1 second (Figure 6a)
- Receiver: Arduino Uno board, Ethernet Shield connects to a Web server and Xbee Shield to receive the signal from broadcaster (Figure 6b)

In Xbee Specification, the signal can broadcast up to 30 meters, but in practice, we tried and discovered the maximum range was just between 10 and 12 meters based on the power of the signal. We did the test by using the ATDB command of XBee to retrieve the signal strength [2] of the last package when the receiver received from the broadcaster. Result of the test can be viewed in Table 1 and the chart (Figure 7)

[2] The signal strength here is the loss not the power of the signal strength itself



(a) Broadcaster

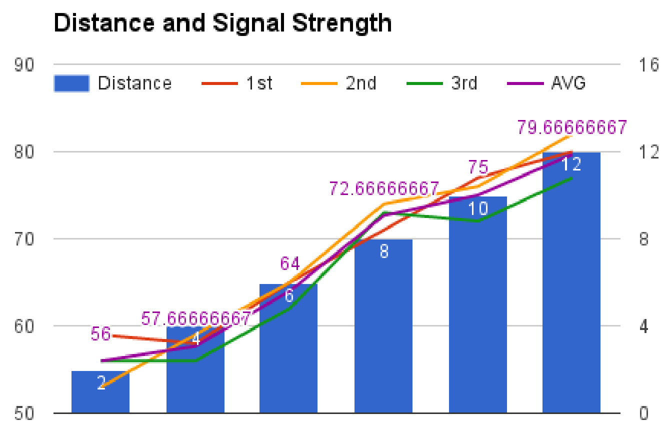
(b) Receiver

Figure 6: Broadcaster and Receiver

Distance(m)	1st	2nd	3rd	Average
2	59	53	56	56
4	58	59	56	57.66666667
6	65	65	62	64
8	71	74	73	72.66666667
10	77	76	72	75
12	80	82	77	79.66666667

Table 1: The relation between distance and signal strength

Figure 7: The relation between distance and signal strength

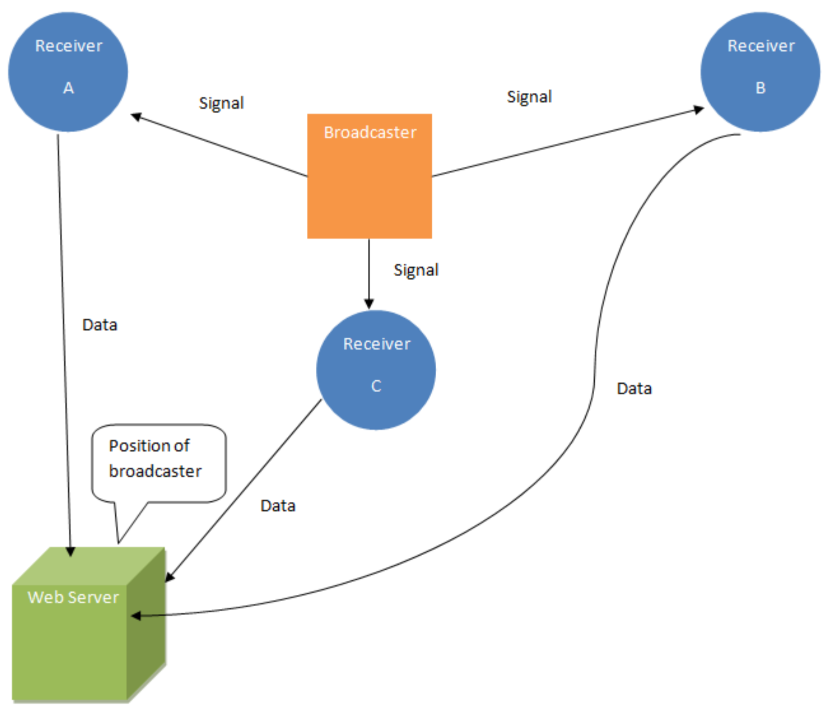


After receiving the signal from the broadcaster, the receiver would retrieve the signal strength through the ATDB command. The receiver now would send the signal strength to a Web server with the help of Ethernet shield (Web server and receivers was in the same network).

When the Web server received enough data from at least 3 receivers. First, it would check the validation of data, like the number of the receiver's id, broadcaster's id...After checking, it would convert the signal strength to distance and calculate the position of the broadcaster in fixed space. After calculating, it would redraw the graphics to show us a map of a room, draw the circle around each receivers and we may see the intersection point where the broadcaster is placed.

We can see the model of our project in Figure 8

Figure 8: Model of project



4 Experiments and Results

4.1 Setup

Broadcasters: The broadcaster would send the signal for every second, the number it sends is also the broadcaster unique id.

- 2*Arduino Uno, 2*Xbee shields, 2*Power supply (battery box if available)
- Broadcast signal: 1-2

Source code for broadcaster:

```
void setup()
{
  Serial.begin(9600);
}
void loop()
{
  Serial.write(1);
  delay(1000);
}
```

Receivers: The receiver would receive the signal from the broadcaster every second. And through ATDB command, it would know the signal strength of the last package it received, it would combine automatically data, include its own id, the broadcaster's id (the number it received) and the signal strength, it would send the data to the Web server through the connection in the same network of server and Ethernet shield.

- 3-5*Arduino Uno, 3-5*Ethernet shields, 3-5*Xbee shields, 3-5*Power supply
- IP range: 192.168.1.[16-21]
- Mac address range: CA FE 00 00 00 0[16-21]

A sample for set up IP and MAC for a receiver:

```
// Ethernet settings
byte mac[] = {0xCA, 0xFE, 0x00, 0x00, 0x00, 0x20}; //Replace with your
    Ethernet shield MAC
byte ip[] = { 192, 168, 1, 20}; //The Arduino device IP address
IPAddress server(192, 168, 1, 2); // IP-adress of server arduino sends
    data to
```

Get the signal strength of the last package through the ATDB command.

```
int receiver_checker() {
  int signal;
  int retval = 0;
  delay(1200); // Wait to get connection
  Serial.print("+++");
  delay(1200); // Wait to run the command
  bool bOK = false;
  while (Serial.available() > 0) {
    Serial.write(Serial.read());
    bOK = true;
  }
  if (bOK)
  {
    Serial.println();
    Serial.println("ATDB"); // The command to get the signal strength
    of the last package the receiver receives
    delay(100);
    while (Serial.available() > 0) {
      signal = Serial.read();
      if (signal >= '0' && signal <= '9') {
        retval = retval * 10 + (signal - '0');
      }
    }
    Serial.println();
  }
  Serial.println();
  return retval;
}
```

Web server: In this experiment, we use XAMPP to build our Apache server, mySQL to store the data and PHP to build the web server. To handle the data received from the receivers, we use JavaScript to calculate and draw the map. One of our main function is the calculation from signal strength to distance. We performed some experiments by increasing the distance 0.5 meter each time and recorded 10 signals in 5 minutes. In practice, the range is between 10 and 12 meters, when you move too far, the signal would drop permanently. In our experiment, we do it in a room 4mx5m and we placed 5 receivers in 5 different positions. The user who kept broadcaster would move around the room. For every 5 seconds, we make a call to the server to know the position. From the Table 2 we deduced the equation for the relationship between distance and signal strength:

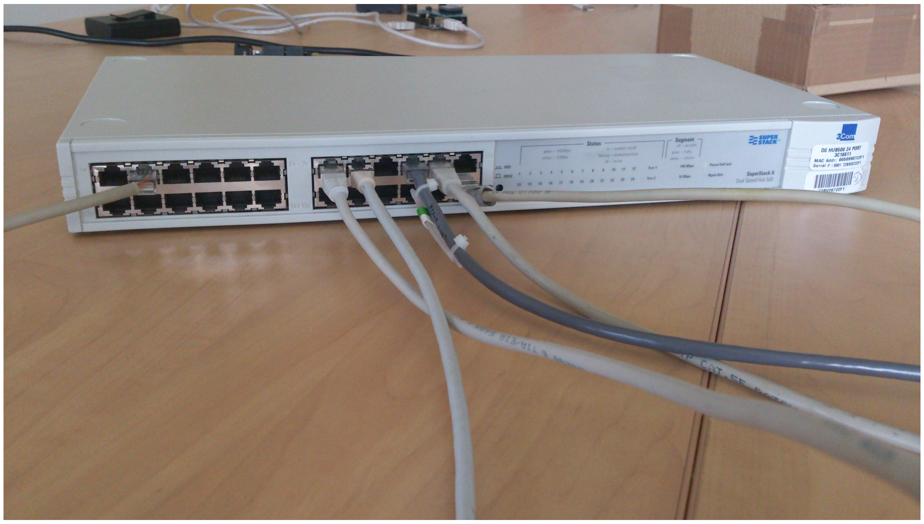
$$signal_strength = 2.55952381 * distance + 28.42857143 \tag{1}$$

Distance	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	AVG
0.5	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29
1.0	33.0	35.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.8
1.5	33.0	32.0	32.0	30.0	33.0	32.0	33.0	33.0	33.0	33.0	32.4
2.0	38.0	33.0	33.0	33.0	33.0	33.0	33.0	32.0	32.0	32.0	33.2
2.5	38.0	37.0	36.0	37.0	38.0	36.0	36.0	36.0	38.0	38.0	37
3.0	37.0	38.0	38.0	38.0	38.0	36.0	37.0	38.0	37.0	36.0	37.3
3.5	35.0	35.0	39.0	35.0	35.0	36.0	34.0	35.0	35.0	34.0	35.3
4.0	41.0	40.0	40.0	39.0	38.0	38.0	38.0	37.0	37.0	37.0	38.5

Table 2: Relationship between distance and signal strength

Network: All of our receivers and our web server needs to be in the same network. We may use a Hub or Switch like Figure 9 to demonstrate the network.

Figure 9: Hub with 6 Network Cables

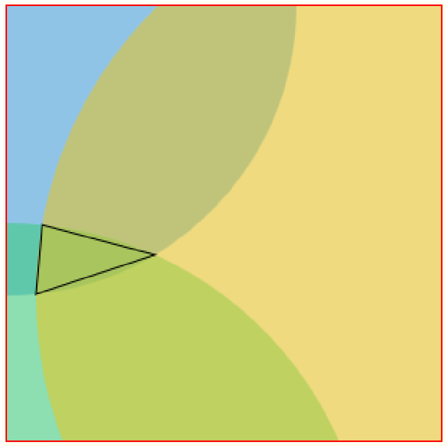


We would need to place the receivers in the room and record exactly its position so we could map it in our programs.

4.2 Results

In theory, whenever we got enough data from at least 3 receivers, and the broadcaster must be inside the cover area of these 3 receivers, we may get an exactly position like Figure 10

Figure 10: Intersection points in the triangle show exactly the position of the broadcaster



But, in reality, we found out that the signal strength is not the same for every receivers despite of the same distance. For example, we may see in the Table 3 and Table 4 is the different number of signal strength for the same distance as we saw in the Table 2.

Distance	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	AVG
0.5	32.0	35.0	36.0	35.0	36.0	35.0	36.0	36.0	36.0	36.0	35.3
1.0	37.0	37.0	38.0	37.0	38.0	37.0	37.0	37.0	37.0	37.0	37.2
1.5	39.0	39.0	39.0	39.0	39.0	39.0	38.0	39.0	38.0	38.0	38.7
2.0	38.0	37.0	38.0	38.0	36.0	36.0	36.0	38.0	38.0	38.0	37.3
2.5	36.0	36.0	36.0	36.0	36.0	36.0	37.0	37.0	37.0	37.0	36.4
3.0	42.0	40.0	40.0	42.0	40.0	40.0	42.0	43.0	50.0	44.0	42.3
3.5	43.0	44.0	45.0	49.0	48.0	48.0	46.0	43.0	44.0	44.0	45.4
4.0	44.0	47.0	42.0	42.0	44.0	45.0	44.0	46.0	44.0	44.0	44.2

Table 3: 2nd Receiver

Distance	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	AVG
0.5	32.0										32
1.0	38.0	37.0	38.0	38.0	37.0	38.0	38.0	38.0	38.0	38.0	37.8
1.5	40.0	40.0	42.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.2
2.0	33.0	34.0	34.0	34.0	34.0	34.0	34.0	33.0	34.0	34.0	33.8
2.5	46.0	44.0	45.0	44.0	44.0	42.0	45.0	43.0	43.0	43.0	43.9
3.0	40.0	42.0	41.0	40.0	40.0	40.0	43.0	42.0	41.0	40.0	40.9
3.5	38.0	39.0	39.0	38.0	39.0	38.0	39.0	38.0	39.0	38.0	38.5
4.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	35.0	36.0	37.0	37.4

Table 4: 3rd Receiver

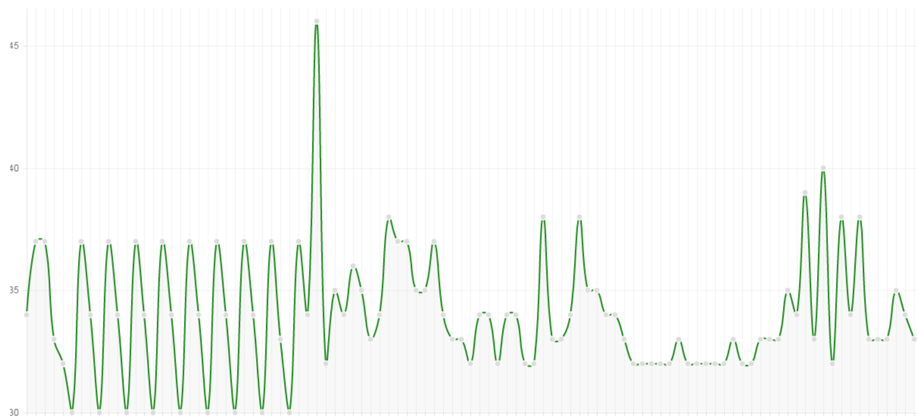
To know where is the problem, we tested with different XBee modules, Arduino boards and Ethernet shields. Exchange one by one and we found out some useful information:

- Xbee Shield inconsistent problem: The Xbee with Antena and the normal Xbee have different signal strength for the same distance. And between each same Xbee module, sometime, they still had the different in signal strength. We all knew the signal could be interfered by the obstructed object like wall or doors, but this problem existed in clear space without any objects between the receivers and the broadcaster.

- Power supply: We found out that when we used directly a power source of 12V, that could be transformed to 5V with Arduino board itself would make the board become really hot very quickly. The power from the battery box was usually not enough and consistent. Our solution: We used some USB cable that connected directly to a USB port of a notebook or desktop to provide power for the receiver. This problem made us hardly to deploy it in large area because the limit of length of the cable.

- Indoor environment: We have a lot of obstructed objects like walls, doors, chairs, monitors affect the power of the signal. To do the experiment, we used a clear room without objects and placed both the receivers and the broadcaster at the same height and no object between them. We recorded with 5 different receivers and 1 broadcaster. The chart of the signal is in Figure 11

Figure 11: Chart of signal strength for the same distance



The signal strength was not consistent from time to time, it was usually change between each receivers.

The problem with Xbee shield made us hard to find a good equation to convert from signal strength to distance. Our function usually was right with 2 or 3 receivers, and fail with the other one.

5 Conclusions

This report presented an alternative way for indoor position tracking problem. The proposed method utilized a combination between Arduino Uno board, Xbee Shield and Ethernet Shield to capture the signal from the broadcaster to send to the center place in the server to calculate and draw the map of position whereas the Global Positioning System (GPS) can not work.

In our study, we use a clear room without obstructed objects that can interfere the signal between the broadcaster and receivers. We applied the trilateration method to find out the position of the broadcaster in space.

Despite of failing to find a good equation to cover almost every signal strength collect from each receivers, we may see a lot of promising in this project:

- Distance: The range between the receiver and the broadcaster was about 10-12 meters is still better than the passive RFID tag with range from 1 meter (3 feets) to 4-6 meters(15-20 feets)
- Economic: 1 receiver cost up to 100$ compare with a RFID reader was usually between 500$ and 2000$
- Controllable: We can easily adjust the source code inside the micro controller and also inside the web server for further work and research.

6 Further work

For further research, we may find a better equation for the relation between the distance and the signal strength to make it more suitable to become a better indoor position tracking system.

And when we already got an approximate equation, we can think further about analysing the data that we collected like we can extract the user's behaviours. From the user's habit records, we may perform some helps for the users, like reminding them stand up for about 10 seconds when they sit too long, or go to drink some water after few hours of working, make the broadcaster works like a medical helper or a reminder to help the user do their works in a healthy and effective way.

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