# GPS Technologies: Indoor Positioning Systems

**ESE 525: Modern Sensors**

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*Abstract*— **There is a growing interest in indoor positioning systems (IPS), also called indoor location based systems (ILBS). This interest has sparked recent development of many indoor positioning techniques. For outdoor systems, data is obtained with high accuracy because of the availability of global positioning signals (GPS). However, for indoor usage, many other signals have been proposed. There is an absence of GPS signals in indoor environments and in environments where the satellite or cellular signals are weak. In this paper, I will consider different technologies and methodologies for indoor localization. In particular, I will look at Wi-Fi, Bluetooth Low Energy (BLE) Beacons, and Geomagnetic Field fingerprinting.**

## I. INTRODUCTION

Indoor positioning systems (IPS) has garnered great attention due to its social and commercial values. Indoor environments are complex and are characterized by non-line-of sight (NLoS) reference objects, the presence of obstacles, signal noises, and changes to the environment. With all these factors, meter range accuracy is still expected in order for an IPS. [1]

There are several different strategies for outdoor navigation using global positioning signals (GPS). However, GPS satellite signals are thinned and weakened when passing through building structures and are distorted due to multi-path propagation [3].

There are several types of signals that have been researched and implemented for indoor localization. Some of these signals include: Wi-Fi [1], Bluetooth Low Energy (BLE) Beacons [2], and Geomagnetic Fields [3]. Combined localization approaches have been implemented by several companies to provide greater accuracy and coverage [4].

In this paper, the sensor technologies that are discussed are Wi-Fi, BLE Beacons, and Geomagnetic Fields. Each technology's operation, fingerprinting, and advantages and disadvantages will be detailed. Afterwards, I use IndoorAtlas and their software platform to fingerprint maps and analyze their effectiveness.

This paper is organized as follows. Section II reviews the general operation of an IPS. Section III goes over the operation of the sensor technologies. Section IV includes some techniques that are utilized to fingerprint maps. Section V talks about some advantages and disadvantages of the sensor technologies. Section VI discusses some applications of IPS. Section VII provides an implementation of the three sensors. Section VIII concludes the paper.

## II. INDOOR POSITIONING SYSTEMS

In this section, I explain how an IPS operates. Figure 1 below, from Senion [4], illustrates three layers of an IPS.

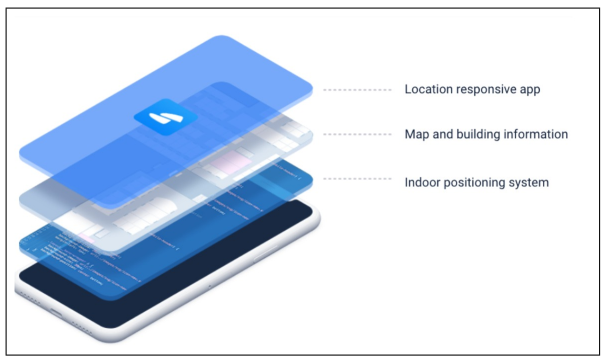


Fig. 1. Indoor Positioning System

The bottom layer consists of the sensor technology inside smartphones that are used to calculate the devices position. The data from these sensors is processed to accurately calculate position. The system itself acts as a location engine. Meaning that it operates in the background to pin-point and retrieve the location of a device. From here, we can get output as latitude, longitude, and floor number of a building [4]. Coordinates alone are not very useful. However, when you put them into the context of an IPS, where you have multiple users, it can be extremely valuable. Section III will go into further detail about this sensor layer.

The middle layer is the fingerprint mapping layer. This is a static layer that we dont want to change often. We can fingerprint maps of the building and load that into the system's database. The maps are created based on a room layout or blueprint for each floor of a building, combined with the data collected from the sensor layer. Section IV will talk about how these maps can be fingerprinted.

The top layer is the application layer. Here, the coordinates from the IPS and the map layer are used to create different features for the end-user. For example, these features can be implemented through an Android app where users can navigate through a building. Section VI will talk more about some of these applications.

The next few sections will talk about each layer of IPS. Later on, you will see the implementation of the middle layer.

## III. OPERATION

In this section, I discuss the bottom layer of an IPS - how the sensor technologies work.

### A. Wi-Fi

Wi-Fi signals are identified from a particular user's device, such as a smart phone. Based on IEEE802.11aj [10], the received signal strength indicator (RSSI) and the media access control (MAC) address are extracted from wireless access points (APs) from the users wireless network. Figure 2 below, taken from Infsoft [6], illustrates the communication among Wi-Fi APs, an app, and cloud.

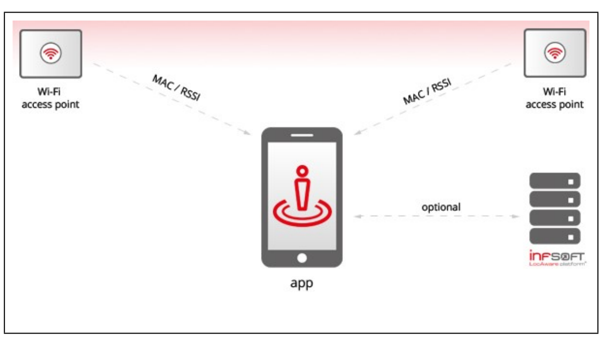


Fig. 2. Wi-Fi Communication

An app calculates the current position based on data from the APs. Transmitter power is calibrated with a corresponding free-space channel model that is established by measuring distance and power at each point in advance. In this way, the rough distance can be estimated for each reference point (RP) [7].

### B. BLE Beacons

BLE beacons are small battery powered devices that transmit a signal in a very small area. They allow a system to react to a user's location when they come within range of the beacon. They are proximity based, rather than exact location.

BLE beacons use channels that are each 2 MHz wide. They span a 2.4GHz radio band that is also used by Wi-Fi. The protocols implemented use small duration messages for smaller power consumption. The release of Bluetooth 4.0 has greatly improved machine-to-machine communication for the Internet of Things (IOT) [2]. There are two types of messages: data messages and advertisement messages. Advertisement messages are important for proximity information, as they constantly broadcast changing information. The RSSI for each advertisement message can be used to form a signature for each location [2]. Frequencies are chosen to minimize interference with common Wi-Fi systems such as internet browsing.

Figure 3 below, taken from Infsoft [6], illustrates the communication among BLE Beacons, an app, and the cloud.

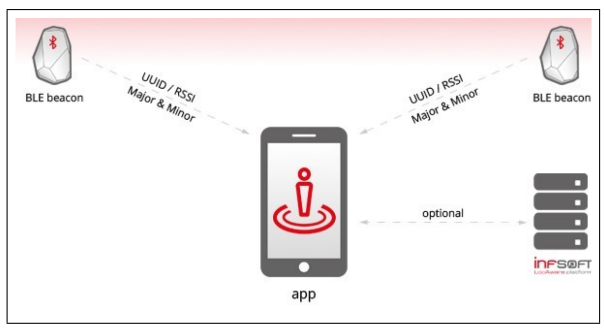


Fig. 3. BLE Beacon Communication

### C. Geomagnetic Fields

Geomagnetic systems make use of the geomagnetic field produced by the Earth's magnetic field that interacts with structural steel and other elements in modern buildings. The geomagnetic field is often used to determine the orientation of a device. The system measures the magnetic field on its own position using a magnetometer, or compass, thats embedded in smartphones. Then, it compares the sensor measurement with a magnetic map that has been created for the building beforehand [3].

Data from magnetic field intensity consists of three components: intensities in the X, Y, and Z directions [5]. According to Lim et al. [5], "the most commonly used units of magnetic field (B) are Tesla (T) or Gauss (G)... the Earth's magnetic field is spatially characterized by direction and intensity. The geomagnetic field intensity ranges between approximately 23,000 and 66,000 nT."

Figure 4 below, taken from [5], illustrates the seven non-independent parameters of the Earth's magnetic field. Declination (D) denotes the difference between "true north" and "geographic north". Inclination (I) is the angle between the horizontal plane and the total field intensity (F). Magnetic field can be represented either in terms of X, Y, and Z coordinates, or in terms of F, D, and I.

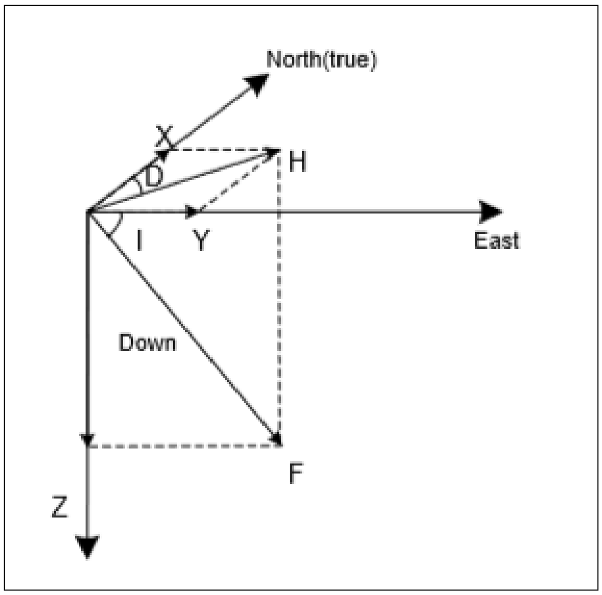


Fig. 4. Earth's Magnetic Field

## IV. Fingerprinting

In this section, I discuss the middle layer of an IPS. Here, I include techniques that are utilized to fingerprint maps.

Fingerprint mapping generally consists of two phases: training and positioning. In the training phase, a fingerprint database is created. For each reference point (RP) location, a signal such as Wi-Fi access points, Bluetooth signals, or magnetic intensities, etc. is measured. From each individual measurement, the characteristic features of a RP is calculated and stored into the database. This cycle is repeated until all RPs have been calculated [5].

In the positioning phase, a device makes a measurement at a location where the position is still to be determined. The measurements are compared with the data that was stored in the database by using an appropriate algorithm. The "most likely" position of the device can then be output [5].

Wi-Fi fingerprinting is done in two separate phases. There is an offline phase, otherwise known as the survey, and an online phase, otherwise known as the query. In the offline phase, a site survey is held to gather a collection of RSSI data of detected Wi-Fi signals. This RSSI data is attained from different APs at RPs of predetermined locations [1]. The fingerprint of the site is comprised of the collected RSSI data. These fingerprints are stored in a database for online query.

In the online phase, a user attains RSSI data based on their current position and sends it to the system's server. Then, the system's server compares the fingerprint data that is stored in the database, with the RSSI data from the user. The user's position is calculated to closely match the user's RSSI data [1].

Wi-Fi and BLE Beacons can be used to infer the proximity of users. S. He and S.-H.G. Chan [1], use ZigBee-based collaborative localization (ZCL). For each user, ZCL calculates a confidence score that is based on a motion model and Wi-Fi location estimation. From the different confidence scores, the system corrects the calculations through redistribution of the scores.

Geomagnetic fields can solely be used to calculate position. Kim et al. [3] proposed a magnetic field based approach that considers pedestrian motion using accelerometers, gyroscopes, and magnetometer in smartphones. When a user's step is detected, a Monte Carlo Localization (MCL) particle filtering can be used to determine the location of a user from any starting position.

## V. Advantages and Disadvantages

In this section, I talk about some advantages and disadvantages for each of the three sensors in an IPS.

### A. *Wi-Fi*

In most cases, it is relatively inexpensive to install a Wi-Fi IPS, because Wi-Fi access points already exist in many buildings. Also, the user does not have to be connected to Wi-Fi, they can just have Wi-Fi enabled. Studies have shown accuracy ranging from 5-15 meters [1]. While that is acceptable, it is not that great compared to BLE beacons or geomagnetic systems.

Each Wi-Fi anchor node can cover a wide area of up to 150 meters [1]. Even though the strength of Wi-Fi signals are strong, in order to achieve 10 meter accuracy with Wi-Fi, many access points need to be installed throughout the building. Therefore, in buildings where Wi-Fi is not already installed, implementing a Wi-Fi IPS becomes expensive.

In Wi-Fi scans, the user's device constantly scans and communicates with the IPS. Repeated active Wi-Fi scans reduces privacy and increases network traffic. In addition, not every mobile device gives access to Wi-Fi scan data. Apple's iOS devices only allow RSSI readings from the APs. Therefore in systems where a good number of users are on iOS devices, it is not advisable to use Wi-Fi IPS [2].

### B. BLE Beacons

BLE beacons are moderately cheap to implement as they are battery operated and do not require a constant source of power as compared to Wi-Fi. BLE beacons transmit a signal in a small radius of about 10-30 meters [2]. Studies have shown accuracy ranging from 1-3 meter while considering different parameters such as beacon rate, beacon density, and power. Lowering beacon density (or the amount of beacons per square meter) reduces accuracy [2].

R. Faragher and R. Harle [2] found that the power draw of mobile device is lower for BLE than for Wi-Fi. They used a Samsung Galaxy S4 with a baseline power draw of 816 mW with the screen on at constant brightness. They found that continuous Wi-Fi scans increased the draw to 1224 mW, while continuous BLE scanning was associated with a draw of 1028 mW. This difference is mostly in part to the simpler protocols of BLE and its optimization for the scan operation. This is because Wi-Fi was not designed with continuous scans in mind.

BLE beacons are also easier to implement because there is not as much constraint compared to Wi-Fi in terms of communication coverage. Wi-Fi was intended for communication, which results in minimal range overlap [2]. However, BLE signals suffer a non-white signal noise that reduces the overall performance of positioning systems. Fading becomes an issue in BLE systems, whereas Wi-Fi systems do not because of Wi-Fi's 20MHz fixed channel (compared to BLE's multiple 2MHz channels) [2].

### C. Geomagnetic Fields

Geomagnetic fields have an advantage over Wi-Fi and BLE beacons in that geomagnetic fields do not require additional infrastructure. Smart phones are equipped with accelerometers, gyroscopes, and magnetometers which are more than enough to calculate position. However, the quality of the built-in magnetometers in all smart phones could be improved [5].

The magnetometers inside each smart phone varies. Li et al. [5] measured the geomagnetic field using different devices. They used four devices, Xsens MTi, HMR2300, Samsung Nexus, and Samsung Galaxy Nexus S. Measurements differed due to different sampling rates. Sampling rates for the four devices were 25Hz, 1Hz, 100Hz, and 100Hz respectively. This can lead to errors during fingerprinting.

Kim et al. [3] have shown that geomagnetic fields can be accurate within 3-5 meters. However, they concluded that geomagnetic fields are better when combined with other technologies such as Wi-Fi and BLE beacons in wireless local area network (WLAN) environments.

Figure 5 below is a chart taken from IndoorAtlas' Research Report on the Indoor Positioning Market [8] that shows market share and current implementations. Here, 298 respondents were asked what IPS methods they use. It is clear that Wi-Fi currently holds the market, but that does not mean geomagnetic fields will continue to lag behind.

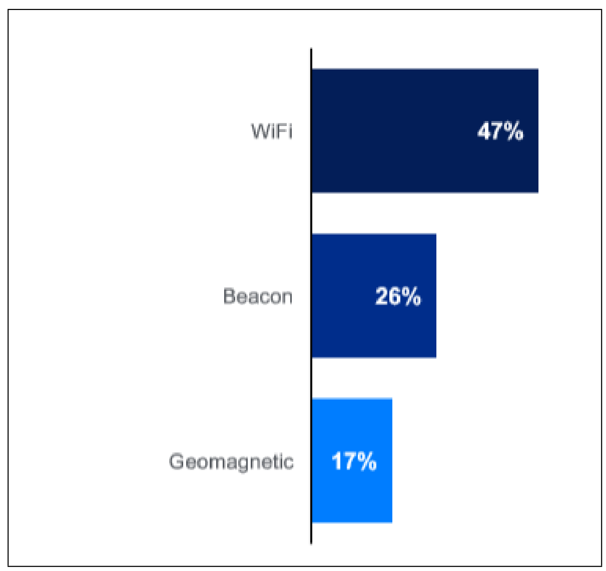


Fig. 5. IPS Market Share (as of 2016)

Figure 6 below was taken from IndoorAtlas' Research Report on the Indoor Positioning Market [8]. The table shows the top two reasons that survey respondents did NOT want to use a certain technology. They were asked, "why has your organization decided not to use beacon/Wi-Fi/geomagnetic as your IPS going forward?"

A lot of companies are already invested in Wi-Fi and BLE beacons and are not ready to trust in geomagnetic

| Beacons | Total |
|---|---|
| Overall cost (purchase, deployment and maintenance) | 36% |
| It would take too long to deploy to all sites (scale) | 33% |
| **WiFi** | **Total** |
| It would take too long to deploy to all sites (scale) | 41% |
| Overall cost (purchase, deployment and maintenance) | 41% |
| **Geomagnetic** | **Total** |
| Already invested in other technologies | 40% |
| It is not a proven technology | 29% |

Fig. 6. Top Reasons Not to Use an IPS Technology (as of 2016)

fields as a new technology. While there is still room for improvement, geomagnetic fields has the potential to out perform Wi-Fi and BLE beacons in terms of scalabilty, accuracy, availability, and cost.

## VI. Applications

In this section, I discuss the top layer of an IPS - some real-world applications.

Some different applications of Indoor Positioning Systems include Indoor Navigation, where the user can accurately navigate throughout a building. For my project, I used Indoor Positioning for shopping malls, which we will see in the next section.

IPS can also be used for people and asset tracking, where the owner of the system can track where people and things are within their system. This can be used in hospitals to track where patients are and where they have been. It can also be used in security systems to monitor the movement of people.

IPS can be used in warehouses to track where supplies or machines are located. BlueRange [9] implements a BLE mesh, where three or more beacons are used triangulate the exact position. Their software allows users to track all of their assets in real-time. In addition to proximity marketing, BlueRange also uses their BLE mesh to implement a “digitized shopping cart.” Here, vendors have the opportunity to see information and analytics on customer behavior and routes.

Figure 7 was also taken from IndoorAtlas’ Research Report [8]. The graph shows the top types of venues that organizations and companies deployed IPS for. In the survey, 231 respondents were asked “What type of venues is your organization deploying IPS in?”

The response is no surprise, as all five venues benefit greatly from indoor navigation applications and people/asset tracking. With the increasing popularity

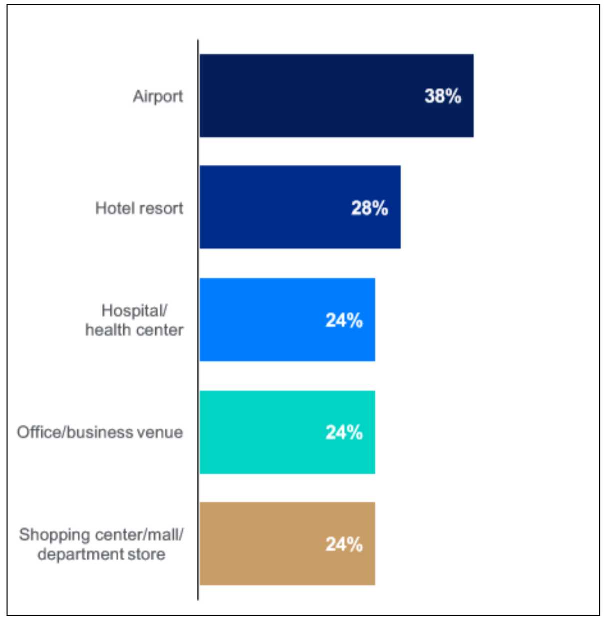


Fig. 7. Top Five IPS Venues (as of 2016)

and efficiency of IPS, I foresee a rise of IPS usage in office/business and sporting venues in the near future.

## VII. Implementation

For my implementation, I used IndoorAtlas’ software and tools. IndoorAtlas is a Platform-as-a-Service company that primarily uses geomagnetic fields for indoor positioning, but also uses Wi-Fi and BLE beacons for further optimization when possible. IndoorAtlas has a free-source software development kit (SDK) and tools that allow you to create floor plans, fingerprint a map, and develop your own Android product for the end-user.

I utilized IndoorAtlas’ technology to fingerprint the first floor of Queens Center Mall, a shopping mall located in Elmhurst, New York. I obtained a floor plan from Google Maps and superimposed it onto IndoorAtlas’ online map creator. I placed waypoints onto every corner and possible walkway, as shown in Figure 8.

For mapping, I used a Google Pixel 3 and downloaded IndoorAtlas’ MapCreator2 Android App. This app allowed me physically go to each waypoint and walk to adjacent waypoints. As you can see in Figure 9, the purple indicates the physical paths that I walked in order to fill up the map. It is important to note that Wi-Fi, Bluetooth, and Location services were all enabled during this fingerprinting process.

After completely filling up every possible path, IndoorAtlas lets me generate maps that illustrate the

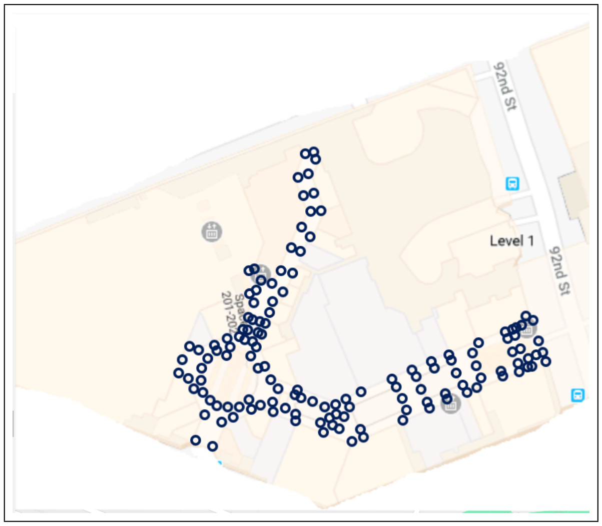


Fig. 8. IndoorAtlas Waypoints

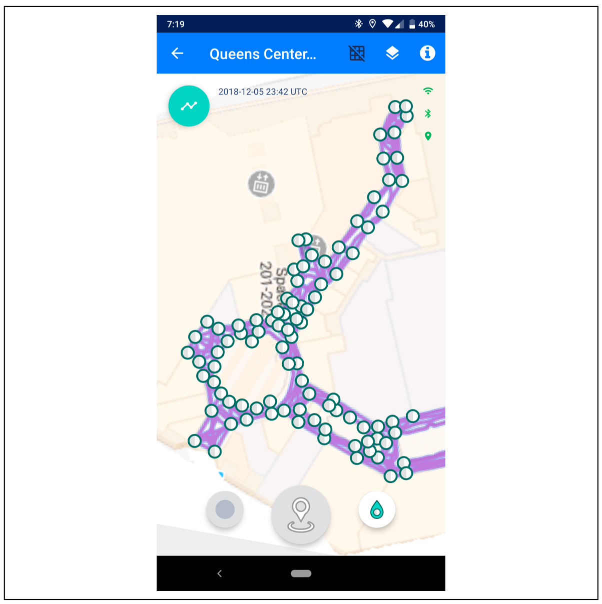


Fig. 9. IndoorAtlas MapCreator2

quality of Wi-Fi, Bluetooth, and Geomagnetic mapping throughout the fingerprinting process. Figure 10 illustrates the Wi-Fi mapping coverage. The Wi-Fi mapping coverage consists of the amount of Wi-Fi scans in the mapping data. In order to obtain optimal coverage, there needs to be dense coverage of Wi-Fi observations.

Figure 11 illustrates the Beacon Environment Quality. This metric depends on the number of beacons detected in the mapping data and the observed signal strengths.

Figure 12 illustrates the Wi-Fi Environment Quality. This metric combines both Wi-Fi and BLE beacons to observe the overall WLAN signal strength.

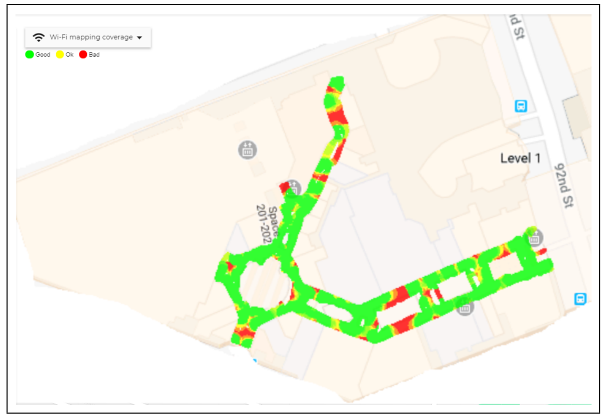


Fig. 10. IndoorAtlas Wi-Fi Mapping Coverage

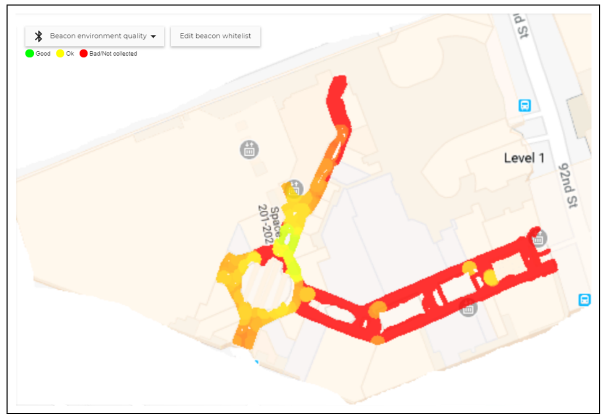


Fig. 11. IndoorAtlas Beacon Environment Quality

Figure 13 illustrates the Geomagnetic Mapping Quality. This mapping describes how well the magnetic measurements agree with each other.

Figure 14 illustrates the final Map Coverage. This depicts the navigable area that has mapped. A total of 3 2,483.9$m^2$ and 312 paths were mapped.

## VIII. CONCLUSION AND FUTURE WORK

This paper reviewed IPS and three different sensor technologies - Wi-Fi, BLE Beacons, and Geomagnetic Fields. IPS is continuously garnering much interest in the industry. There are several companies that have already implemented their own IPS and have distributed it to various venues. Each IPS technology has its advantages and disadvantages. Companies have combined different sensor technologies in order to produce high-quality fingerprint mappings.

IndoorAtlas' software allowed me to successfully fingerprint a floor of a shopping mall. The results show that Wi-Fi and Geomagnetic Fields perform incredibly well in a shopping mall environment, while BLE beacons were sub-optimal. The generated map can be

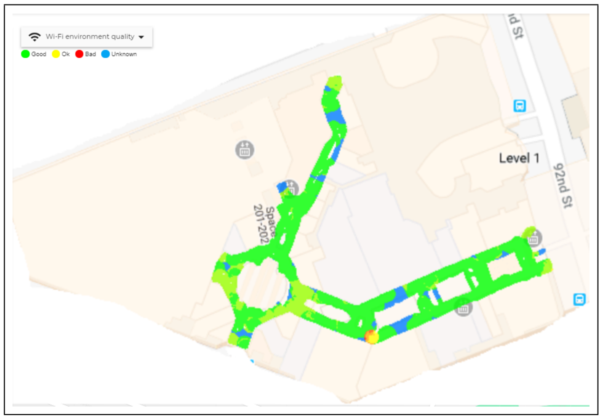


Fig. 12. IndoorAtlas Wi-Fi Environment Quality


Fig. 13. IndoorAtlas Geomagnetic Mapping Quality


Fig. 14. IndoorAtlas Map Coverage

referenced in an Android App for indoor navigation.

In the future, additional floors of a shopping mall can be fingerprinted to determine how well the signals perform in relation to other floors.

## ACKNOWLEDGMENTS

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