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A guide to indoor localisation using different wireless technologies

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Abstract: Software, and hardware work together to make up the Internet of Things (IoT). The study finds a safe way for the IoT to enter your home. We can see different ways to move around inside with the help of a radio signal strength indicator (RSSI) and bluetooth low energy (BLE). This is done since global positioning system (GPS) does not work well inside. The study aims to determine how well iBeacon apps can help people find things inside. It checks whether the weighted centroid localisation (WCL) and positive weighted centroid localisation (PWCL) ways are better or worse. When mapping filters are used, there are also more situations to look for them. There are four different ways to find the 47 test spots. When there are different ways to do something, things are set up even less often. Because it's only off by 1.44 m, the HYBRID-MAPPED way is almost always the best.

Keywords: theoretical foundations; methods for placing iBeacons; fingerprint location; data acquisition and preparation; performance comparison.

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Biographical notes: Leo John Baptist Andrews is an Accomplished Educator and Researcher with a remarkable 15-year journey across diverse educational landscapes in Africa, including Liberia, Botswana, Tanzania, and Ethiopia. He is currently holding the esteemed positions of Associate Professor, Registrar and Head of the Department (HOD) for Information Technology and Management at BlueCrest University College, Liberia. His academic qualifications includes a Post Doctor Fellowship in Information Technology from Lincoln University College, Malaysia, PhD in Information Technology from Amity University, Rajasthan, MSc in Cyber Security from Mizoram University, MEd in Higher Education from Botho University, MTech in Computer Science and Engineering from SRM University, MSc in Computer Science, BEd in Computer Science and BSc in Computer Science.

1 Introduction

Many services are now possible thanks to digital networks and the fast growth of smartphones over the past few years. Some help you find things, find your way, and keep track of them. Location-based services (LBSs) are becoming more important in business and industry as more people use mobile apps. Many believe GPS and other global navigation satellite system (GNSS) are the best ways to reach their goals. Many people find that these things work great when they are outside. Translators must be made in a new way to work well even when they break. You can find out where you are with any service mostly because fewer people are going out (Zhang et al., 2008). It should be possible for the new computer to join the Wi-Fi network that's already there. People have used the Internet of Things (IoT) more in the last 20 years. IPSs are now more important because of

this. This is mostly because IoT is used inside most of the time. People have also talked about many different tools that can be used to look inside. No matter how hard it is inside, these will help you find people and phones.

Businesses like the IoT because it has an intruder security system (IPS) and an indoor location-based service (ILBS). You should consider how much tracking tools cost and how to use them. They should do something helpful. However, this IPS study is not very in-depth, so many different test methods had to be picked (Bahl and Padmanabhan, 2000). On the other hand, only some parts of the system model are used when finding a place inside. Many things are linked and affect how well the tracking system works. This is true because these things do not change how well the location system works. Today, indoor localisation is used for many things, like finding your way

around big buildings like airports and shopping malls, making sure products are of good quality, keeping an eye on the elderly or disabled, making sure therapy works in medicine, providing location-based services to improve the user experience, figuring out how to get around in city parks, figuring out how to use energy in smart buildings based on occupancy, and guessing building occupancy for emergency management (Hossain et al., 2007).

These things are another reason to stay inside. With bluetooth low energy (BLE), many people can find their phones inside stores (Ficco et al., 2014). That's what makes this tool different from others. Another good thing about BLE is that it does not need as much power as Wi-Fi. Wi-Fi devices need power every once in a while. This is one of the rules for where to put the tools. That was the first thing that came to mind. This one is different because the ad unit always needs to know where it is. In this case, the machine is only on while being set up. When BLE came out in 2010, it aimed to improve Bluetooth. When Bluetooth 4.0 came out, changes were made to the BLE to send data more slowly and use less power (Obeidat et al., 2021). This was done so that low-cost electronics that do not need more power could use it. Finding BLE devices is helpful when finding something inside.

Many new phones and computers already have BLE built in, so it's easy to find and use (Maddikunta et al., 2022). It's BLE, and it sends information but does not get it. Beacons are used by companies like Apple, Google, and Facebook to make new products and rules. People use them to get around, get close to things, feel things, and do similar things in schools and businesses (Zafari et al., 2019). It does not cost much or take a lot of power to send a BLE signal. They're simple to set up and keep charging for a long time. People know them for having low prices. All of these good things about BLE tech make it great. It lets you touch someone from far away for the first time. With this tool, fewer news sources can reach more people. It's easy and costs little to get more people to use the app now (Gupta et al., 2022). It can be used in many writing tools because it has many useful parts. To be exact, it can find only 1 m away spots. It's more important than ever to put things where they belong. Many services and apps need always to know where the user is to work. They can learn new things, play games, or ask for help if they need it.

Now that smart towns and the IoT are bigger, it's more important to find things. What about the business end of healthcare? We need to know exactly where we are to know what alerts to send and stay safe (Hayward et al., 2022). GPS lets People see what's happening around them and find out where they are. But it's harder to get where you're going if you do not have GPS or are near or in a place where satellite service is bad.

2 Related work

A few pieces look at how the different ways to put things inside are alike and different. We looked at depth, angle,

and closeness as different ways to find things inside. Their study also looks at several success factors, such as how accurate it is, how much it costs, how hard it is, how safe it is, and how big it is. Some technologies that could be used are GPS, radio-frequency identification (RFID), wireless local area network (WLAN), Bluetooth, UWB, and cellular. They looked at many different methods from the point of view of a device in their in-depth study of wireless indoor localisation methods. People who wrote the paper looked at what made systems that needed devices different from systems that did not (Bibbò et al., 2022). They looked at how accurate it was, how much it cost, how much room it had to grow, and how much energy it used. He and Chan looked into the Wi-Fi fingerprinting method with two main goals: improved tracking methods and practical ways to use it in real life.

Signal patterns in space and time were used in several different ways that researchers looked at. To find out how accurate it was, how easy it was to get to places in the middle of nowhere, and how much more information was needed to figure out where something was and what its limits were, it looked at things like these (Singh et al., 2023). Researched how visible LED light technology can put things in place. Some systems they looked at were Wi-Fi, BLE, and GSM. They rated the systems based on how accurate, reliable, expensive, hard to use, and able to connect to systems that were already in place (Chen and Jia, 2014). They also looked at how well some other ways of translating worked. Much attention was paid to Wi-Fi cell networks when comparing the different ways to find out where you are inside. They looked at a lot of options in their in-depth study. Some were for business, and some were for research. The choices were made based on price, speed, dependability, difficulty, user tastes, business needs, and limits. They found the same things that other studies had found.

Each answer has a unique set of tools that only work well in certain situations. This piece closely examines all the different home mapping apps for smartphones. This research looks into IPSs and the FDA to see if they can be used for feature extraction in this area. Smart buildings, emergency services, and services that depend on your location can all use inside positioning (IP). This is why it's getting more attention right now. This research reveals two main types of intrusion prevention systems (IPSSs) that use RSS and Wi-Fi, which are in line with models of tracking and path loss (Brena et al., 2017). The route loss model-based method looks at the link between RSS and distance to find the thing that is the goal. This distance-based method cannot give the right math numbers because too many things are going on inside. Another way to find out where someone is inside is through fingerprints, which is getting a lot of attention. That's all there is to it.

It works better than the distance-based method in more complex cases. Wi-Fi-based RSS tracking is also becoming more popular because it has many benefits, such as being free to use, safe for all users, and easy to set up. It's also

getting more attention from other people (Hailu, 2025). A very important part of platforms and sensor networks in the IoT, and it can be used to talk to many different things. This plan has two main parts: Get RSS fingerprints from each Wi-Fi access point (AP) in several different places (Chin et al., 2020). This can help you make a radio map or fingerprint library. Next, you must teach a forecast model to find the link between the signal and the position.

This method is wrong since creating Wi-Fi maps can cost money. Radio maps are now faster and easier to use in several ways. People can help with positioning and maps using Wi-Fi, but each method has rules and limits. Also, remember that most Wi-Fi networks are designed for talking, not for finding places. These networks need to be improved so they work better and last longer. On the other hand, when internal settings change, the fingerprint method still cannot offer stable and accurate placement.

3 Materials and methods

3.1 Theoretical foundations

3.1.1 Selection and placement of transmitters

Radio-frequency identification (RFID), IEEE 802.15.4, and other new wireless standards make it easy to create new ways to find things inside. Table 1 shows how well these three tools do their jobs.

Table 1 Three distinct pieces of internal routing hardware are compared

	<i>Wi-Fi</i>	<i>RFID</i>	<i>iBeacon</i>
A coverage	40 m	10 m	50 m
Cost	High	Low	A little high
How much power is used	High	Low	Low
Wi-Fi speed	1.7 G	140 kb	1 M
Time on battery	Several days	1–2 years	1–2 years
Accuracy in positioning	2–3 m	1–2 m	1–2 m

An iBeacon will be used to get the data for this test. With this gear, you can send RSSI texts up to 50 m away. After five years, the battery might not need to be changed. You can do both of these things. The thing that Apple and the Estimate team made together is called an iBeacon (Khodamoradi et al., 2024). It's ready for them to use right now for school. In the past few years, the iBeacon tag has gotten much more attention from people studying things. Smart tools and other things can be put in homes with this tech. The Bluetooth signal came from the same things so that the study's goals could be met. These three things were bought for the project and will be used.

3.1.2 Methods for placing iBeacons

A company that keeps track of people inside the company made this tech. The people who to help a lot of people, you need to learn this. One way to do this is to develop a better plan to cover more ground with the fewest iBeacons. Find the best spot for three iBeacons that are close to each other. This is one of the most important things being looked into right now in this field. In 2018, Dr. Rezazadeh and his team did a study that showed this is a good way to use this tech. This is one of the main sources for this work. If you use the triangle with straight sides as a guide, it works much worse when you just put the iBeacons anywhere. Chance is not a good thing to use. The way shown works a lot better. This is what the fresh study says. You need to put things in the right places to get the most accurate pictures of where you are. This time, it's easy to see why. Another word that needs to be thought about is this one. Several things could cause it. Many things could steer you wrong, such as:

M: Mapping error

A: Error in the localisation algorithm

B: Node types that iBeacon uses

P: Beacon location

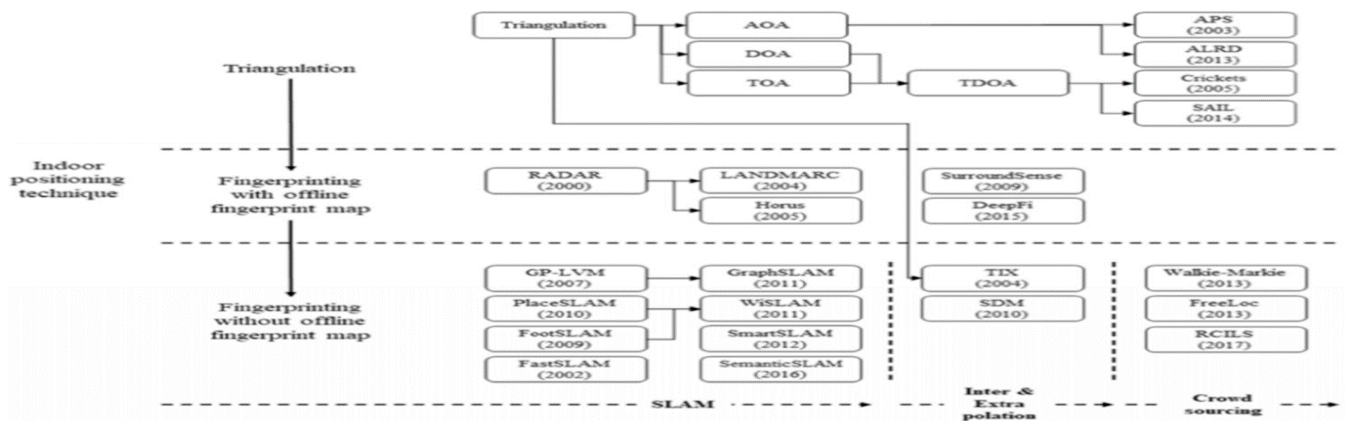
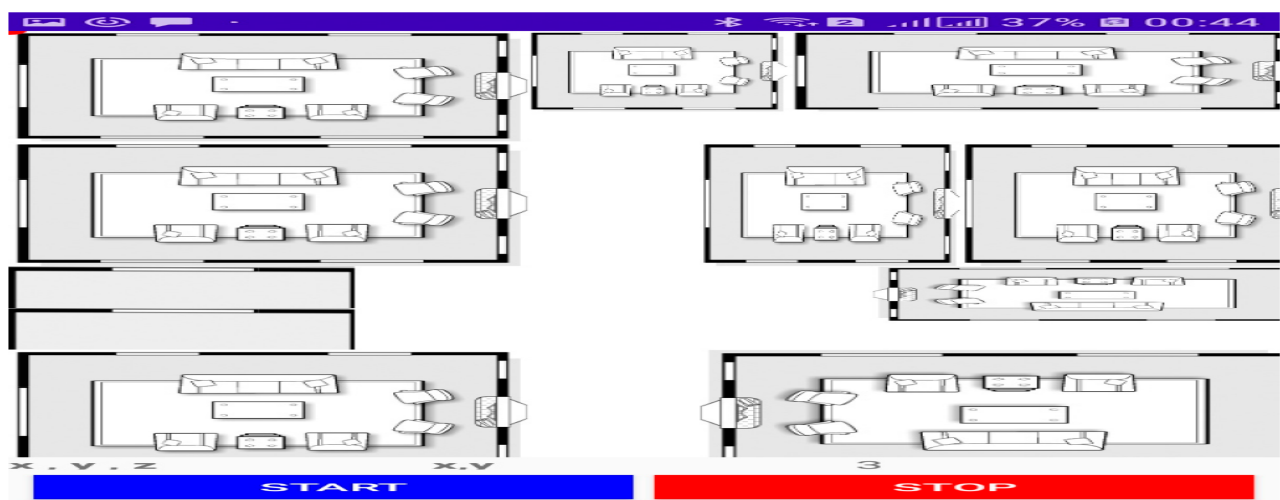
$$L_e = f(M, A, B, P) \quad (1)$$

Locating receivers on the spot

Today, there are many ways to read radio waves and discover where things are in a network. Finding your way inside will work better if you add iBeacon devices. Through iBeacons, our phones can tell where other people are. After that, there are many things we can do to help them get to their goals as quickly and safely as possible. Things can connect to the web.

3.1.3 Fingerprint location

Some people think fingerprints are the best way to find someone. In many cases, RFID tags that can read fingerprints are used to keep track of people inside buildings. Yes, this is true since Wi-Fi and Bluetooth are used inside. It's because there are waves inside. A lot of people can get them. This method is great because it's simple to follow. In the business world, fingerprints can also be used with Wi-Fi or Bluetooth data to find out where a device is on the inside. A lot of information was saved in the core after the local map was set up. That is, the signs that each thing sent could be linked to information from the past. A map could then show where everything was. There are many learning places, like the whole house or just one room. Remember that fingerprint tech is always good and safe. In Figure 1, you can see how fingerprints are made. It tells you various methods to utilise them.

Figure 1 Algorithms used in the fingerprint method**Figure 2** The application's user interface is built on the business workspace (see online version for colours)

3.2 Method

Before TVs and the web, there were many ways to search the house for things. It has to do with the study's goal and the tools used. Many people think that fingerprints are the best way to do business. Maps of the real world use a grid line. This is what the job is all about. This is what the job is all about. In real life, forty inches are between these two sets of numbers. The first thing that needs to be done is to set up the test room. The next step is to send training data to a computer and record it. This is what the app in question does 47 times. It gets 47 points because it has a hallway and three study rooms. You can get to 47 different places by following the queue. You can get the training data in a different step. After that, you can keep track of them with four different apps. The tool is now being used to see the whole area. With this app, you can move around and send your iPhone or iPad to the goal point. Based on what it sees, it is taken to four different places after that. Every mistake is being kept track of at the same time. Last but not least, once something has been found by mistake, the best way to find it in the app can be changed to the normal way. It's easy to get around if people walk around it.

To do this, four main phases are first defined as follows:

- 1 *The first phase:* Offline section, to collect training data from the environment.
- 2 *The second phase:* Online section, implementation of locating algorithms.
- 3 *Third phase:* online section, combination of second phase algorithms and debugging.
- 4 *Fourth phase:* calculation of measurement error.

3.2.1 The first phase: the collection of training data in the offline section

This part involves getting training data from 47 places around the world and sending it to the computer. The data is then put into a database so that it can be used with the fingerprint method to help find people.

3.2.1.1 Selection of the testing environment

The study occurred in a part of a business building, as shown in Figure 2. Everything in the experimental area is

made of glass, which might be good because it keeps noise out. Brick, cement, and clay walls can tell the difference between the messages they receive and block out certain types of noise.

3.2.1.2 Transmitter positioning (iBeacons) using the CIP method

Figure 3 shows the area that was looked at. Three iBeacons, goods that Apple and Estimate worked together to make, were used and put in three sides of the room to make an equal-sided triangle. The picture below shows this.

3.2.1.3 Designing and implementing back-end for receiving and storing data

In this case, a system built on the Linux kernel was made to store a PostgreSQL database sample of signals in the offline area. Laravel and a web server called Nginx were used to make this happen. It is then decided to make and use an Android app written in Java so that the data from the

antennas can be sent to the computer and saved there. This is done in the following way:

- 1 Commence
- 2 Get the coordinates of the point you want to find
- 3 Get about 300 signs for every emitter
- 4 Send the report to the server
- 5 The end.

Figure 4 shows the main structure of the program. The program has online and offline parts that can be used to get information and find things.

3.2.1.4 Sampling

Forty-seven places were chosen as samples for the training data keeping process. These include the main hallway, four rooms, and other places. This choice will be made after the server, databases, and trial tool are set up. The sample step's user interface is shown in Figure 5. It lets you choose where in the world to get RSSI data, which helps with translation.

Figure 3 Representation showing the position of the transmitters (see online version for colours)

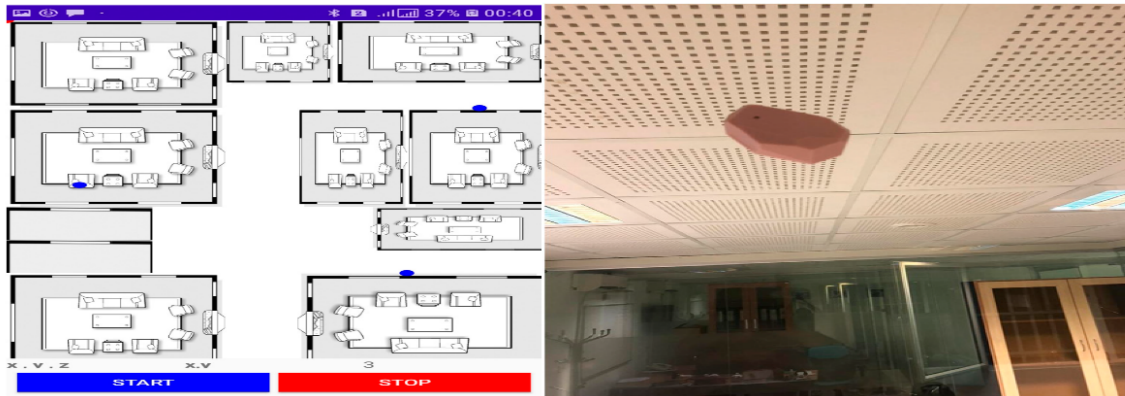


Figure 4 Architecture of application

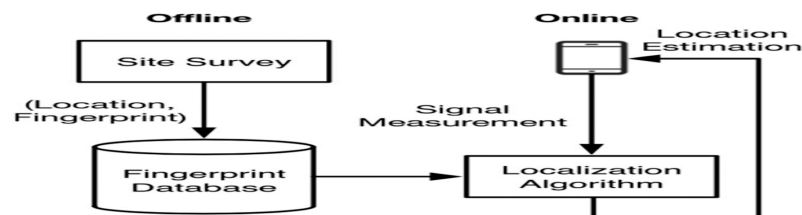
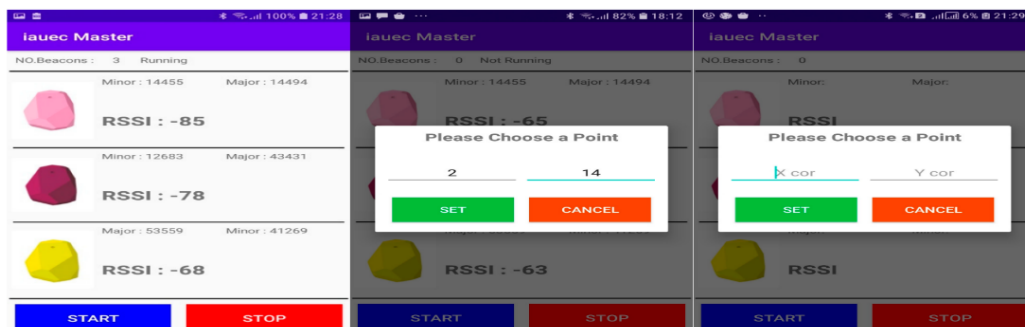


Figure 5 Application's user interface during the sampling stage (see online version for colours)



3.2.2 The second phase: the implementation of locating algorithms

The putting inside can be done in four different ways during the second part of the surgery. You can change the back-end method and make an app to do this. In the first two ways, fingerprints cannot be used to find out where someone is. The three ways to find out where someone is are all used together. You should use them all at the same time. The best way to do it is with your fingerprint. It can now find the goal point in more than one way based on the ways that were asked for. So this is why: the tracking app now works great.

3.2.2.1 Location with weighted centroid localisation (WCL) algorithm

Weighted centroid localisation (WCL) is being looked at as the first way to track in this study. It's done this way so that it can be used to rate other creative ways to study this subject. In this way, the place is checked out without changing the plan made for it in the study.

$$p(si) = \frac{\sum_{f=1}^{N_r} (RSS_{if} \cdot b_f(x, y))}{\sum_{f=1}^{N_r} RSS_{if}} \quad (2)$$

Equation (2) shows how to find the spots in space if you use the WCL method.

This is done by increasing the message strength of each source by its X and Y counts. Next, find the numbers by adding and taking away. It's based on how strong each sign is. Read about the place that was found on the map as the last step. Some of the things you sent us were read to help you understand this method better.

3.2.2.2 Locating with positive weighted centroid localisation (PWCL) algorithm

The points found so far are leading to bigger signs in this part. Because it's not good enough, the WCL method has been made better. Your RSSI will be mostly bad after you get it. As the negative numbers get bigger, the warning will get stronger. This is why the WCL method usually finds the answer in the middle of the triangle. This is done because the texts can be anywhere from -40 to -100 . This is because you can hear different ideas here. Finally, most people choose the person who did the best.

$$P(si) = \frac{\sum_{f=1}^{nr} (RSSI_{if} + 100) \cdot b_j(x, y)}{\sum_{f=1}^{nr} (RSSI_{if} + 100)} \quad (3)$$

The third equation shows how to use the positive weighted centroid localisation (PWCL) method to find places in space.

3.2.3 The fourth phase: measurement of locating error

One mistake was found. A table called trace_logs keeps track of the four ways to find something. These places are used by sending the goal points and speech signs to the computer while they are there. Which place on the Cartesian coordinate line did the programs find? How far is the goal point from that point? The Euclidean distance method is used to find that distance. What goes wrong? How far away is the point being looked from the point being found? This is where the goal point is: (X_t, Y_t) . Position algorithms found this point (X_i, Y_i) .

$$R = \sqrt{(X_t - X_p)^2 + (Y_t - Y_p)^2} \quad (4)$$

Figure 4 shows how to find the Euclidean distance. From there, 0.4 is added to the Euclidean distance to turn the wrong scale into meters. Remember that 40 cm is one unit of Cartesian numbers when you do this. This process is done four times for each point, and the results are saved in a table.

4 Experiments and results

This part first shows how to prepare for the trial by putting things together. Then, the method is shown and compared to other well-known machine learning methods.

4.1 Data acquisition and preparation

Three different people in three different places gave them those things. It all took place in a city flat. This tool was used to learn everything. Three people worked together to find this. Everyone wore a Sony Smartwatch 3. It had 512 MB of RAM and four cores at 1.2 GHz. Plus, it had 4 GB of space. The tests and the work done online were done on the same computer. Each helper chose a place to look. A man in his 49 s was the first to offer to pick six rooms (Belmonte-Fernández et al., 2021). A man in his 30 s who picked five rooms came in second. The third person to offer to help her was a 26-year-old woman who picked out four rooms. They were given in real places to make the tests look as real as possible. People thought that would happen since they could get the test and training files at any time. It was also thought that people had connected their tools to different places. Everyone in the class did well on the test and got a 100. People can get Wi-Fi fingerprint training files in three different ways. This stuff was bought by people who use it.

How long does it take to get 100? The online part of the tool works well, which we like. For the first method, everyone had to stand in the middle of their room and record 100 samples of the Wi-Fi signal. The second person did it by picking 100 Wi-Fi samples at random from all over

the room. Third, 100 samples were taken from the drug users in the room where they were most often found. It was not clear where the person was in this last way. This person might be watching TV while sitting in a chair or lying on the couch. Many people who used it said they did not change where they took the test. We got 300 samples of Wi-Fi from all over the place because of this. People who used it said it took about two minutes to get 100 samples from each room. In other words, it took them an average of over a second to get each sample. Each person got their test results at a different time. Several people mapped it at different times, but one person did it all simultaneously.

4.2 Performance comparison

You do not always need to be smart and good. It's already set up, so we do not need to show you how to use Wi-Fi. Our position method is tested against four well-known machine learning methods to see which works best. These are the Naïve Bayes (NB) method, the KNN method, the Random Forest (RF) strategy, and the A* method. KNN is often used to find something inside. This is how our method (HMM) compared to some of the most common ways to find Wi-Fi inside. KNN, RF, NB, and MLP are a few of these. Many people use the Euclidean method to figure out

how far something is. This is what my friend and I did. RF is a tool for machine learning that works well in all of them. There are lots of pretty trees. We built the forest 100 times for each case using everything from the study. It was told to learn at a rate of 0.3 and go backward at a rate of 0.2 for 500 epochs. Half of them hid traits and groups.

That's what machine learning is. It does not need to be changed because NB is a tool for making things based on Bayesian statistics. These tools that Weka gave us work. The best chance room was always looked at. The odds of each sample taken one after the other were added up to get this answer. People do not have to vote, so it works better. That's all there is for person 1. Figure 6 shows the tests that were done on it. That will help them determine how many samples they need to sort the things. That changes in this scene. How well it worked can be seen by how many samples were sent to the right group. Every Wi-Fi library room has 100 samples. This is what the model is based on. They stood in the middle of the room and moved around without a plan so most people could see them. That's how the person who made the first plan learned about the news that would help them train. Our largest study group had 20 people. This was done to see what would happen to speed as the number of samples increased. Remember that most of the tricks in the books only need one example.

Figure 6 Comparison of user 1's performance. The successful rate (%) is shown against each curve's sample size (number of consecutive samples used for classification). To create the model, each Wi-Fi database included 100 samples per room (see online version for colours)

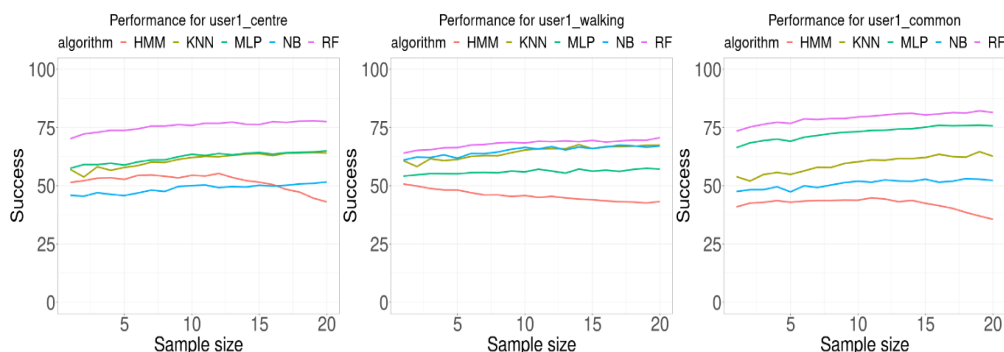
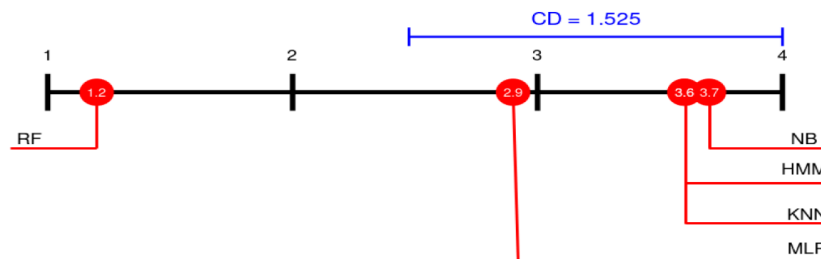


Figure 7 The performance of different approaches is compared using the Nemenyi test (see online version for colours)



The abbreviation for critical distance is CD.

The given method (HMM), which is based on using HMM for indoor localisation, did just as well in the tests as the other algorithms used to compare it. What method was used on all twelve datasets most of the time? There are two types of tests that you can use. The α number was 21.6, and the p-value was 0.0002407. We do not agree that each way is

the same. Neomenyi's test had to show that the chosen ways of putting things together did not work well with each other. Check out Figure 7. It will help him figure out how well he did on his test. In other words, the first one (HMM) and the next three (NB, KNN, and MLP) are not that different from each other. Also, there is no such thing as critical distance

(CD). This means the changes are unimportant enough to be named and tracked. Table 2 shows that we used a different significant number for the z-test. It's 95%. The RF method seems to be the most likely to work. Think about how far away something is. The MLP, HMM, KNN, and NB algorithms are not very different.

We picked the user2_center database and the test database that goes with it to see how much it costs to do things differently. Five cases made up each of the time series in the test set. Everyone was put into a group as planned, and time was always kept track of. These steps were done 100 times for each way to make sure it worked. The average time and mean squared error for each set of time series are shown in Table 2.

Table 2 The z-test results were used to evaluate the proposed method (HMM) against the alternatives

Approach	z-Value	Importance
KNN	0.0	NS
RF	-4.174	$p < 0.01$
NV	0.149	NS
MLP	-1.192	NS

NS stands for "not significant".

5 Discussion

People think that Wi-Fi waves based on RSSI can join very quickly. RSSI tells you inside where something is. An HMM can copy the Wi-Fi signal with this part of the signal. This thought has been checked out many times and always comes out right. But it does not happen often. To put it another way, we must first look at the given method for the inside position. The study's main goal is not to find the best settings for every situation but to show that the method suggested for using Wi-Fi to find your location inside works. That's what this work is meant to do. You can change things in the training set, such as the number of secret states and RSSI Wi-Fi samples, to see if the method works better or worse. When the room changes, any way to keep track of Wi-Fi inside is less useful. We need to find out more about this. One way to change the space around you is to move chairs or WAPs. The goal was to get results as close to real life as possible. Some results might not have been identical if the subjects had done other things. It would be helpful to have a test where two people in the city share a room but act differently.

6 Conclusions

Wi-Fi tracking was used to show a new way to get around inside. What does the HMM tell you about the RSSI Wi-Fi signal? It keeps track of how it changes over time. This is what the method is based on. Over time, more samples are added to the forward loop. To find the person, it checks the likelihood that the samples are real. Many tests were carried

out in three real places, all of which were flats in towns. It worked a lot better because they used so many more examples when they taught. It was compared to a well-known and widely used machine learning method to see how well it worked. It worked just as well as, or even better than, other well-known Machine Learning ways to find where something is inside. In one case, the speed started to slow down after 25 runs. After that, it went up very quickly. It was about the same after fifty shots as it was after 15. Not having a healthy circadian cycle has been linked to many new studies that show brain illnesses. Some people are not as smart when they change how they walk inside and outside. Some people might get sick or mentally ill because of these changes to the house. We can now tell if older adults who live alone are crazy since we can better monitor them.

Conflict of interests

All authors declare that they have no conflicts of interest.

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