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Wi-Fi-based Indoor Localization for Location-based Smart Notification

An Initial Study and Deployment

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***Abstract*—Indoor localization has been researched widely in the recent two decades due to its wide range of applications such as navigation, elder care, advertising. This work presents a utilization of indoor positioning for a location-based smart notification purposed, deployed in a meeting room booking application. Our localization method is based on Wi-Fi fingerprint, tailored to our application needs to alleviate the drawback of its tedious offline phase. The initial implementation is done with limited number of recorded locations. The testing shows that the meeting room booking application works well, with the localization detecting user's location correctly aside from when poor signal condition occurs.**

***Index Terms*—Context-aware System, Fingerprint, Indoor Positioning/Localization, Smart Notification, Wi-Fi**

I. Introduction

The concept of localization or positioning for indoor environment has been gaining traction in the recent two decades. Wide range of works on indoor positioning tackle various aspects such as the physical technology, the position tracking methodology [1], [2]. While there are wide range of applications that can take advantage of indoor positioning, its implementation was mainly hindered by the lack of infrastructure. On the other hand, outdoor positioning system has been implemented and widely used for decades, covering areas globally using satellite as their positioning infrastructure. Such systems are classified under the term Global Navigation Satellite System (GNSS). There are only limited number of GNSS deployments as it requires huge amount of investment for its satellite infrastructure, namely GPS, GLONASS, Galileo, and BeiDou [3]. However, the same satellite infrastructure is not applicable to the indoor positioning as it lacks the accuracy required in indoor environment [4].

To track in an indoor environment with adequate accuracy, the system needs to rely on wireless technology whose signal characteristics are designed for indoor or urban environment [2, 3]. With the development of multitudes short / medium range wireless standards (that is of WPAN, WLAN), indoor positioning system has the choice of leveraging those standards along with their existing infrastructure. For example, Wi-Fi network with decent coverage can be found almost anywhere in an urban area or a building [5]. Such ubiquitous indoor network could not be found easily a couple decades ago. Cellular network infrastructure has also evolved, deploying smaller nano and picocells to extend reach and service quality inside public places such as shopping malls, office buildings [6]. Bluetooth beacons infrastructure, while not readily deployed as widely as Wi-Fi and Cellular, can be implemented with reasonable cost. Furthermore, these wireless technologies can be leveraged to track objects and people due to the omnipresence of modern smartphones which include those wireless modules, hence allowing the tracked entities to interact with the positioning system.

Methods of localization in general can be classified into static (pre-recorded location signatures / fingerprints) [7]–[10] and dynamic (calculating distances to several anchor points based on received signals) [11]–[13] approaches. There are wide variety of methods on either approach, each with their pros and cons which can be tailored to the application. As with outdoor positioning, indoor positioning can be leveraged for various purposes such as indoor navigation [14]–[16], surveillance of sick and elderly people [17], [18], and location-aware advertising [19], [20].

Smart campus is one example of suitable environment to integrate the indoor positioning technology into. Within a campus, large number of students, staffs, and lecturers move around the campus in different hours for classes, labs, or meetings. Depending on the period, those individuals' schedules or appointments could be packed. With smartphones, reminders and emails can be conveniently used to keep track of those schedules. However, they also generate lots of notifications that may lead to interruption overload [21]. By utilizing indoor positioning, notifications around the scheduled activities can be filtered, and presented to the user only if necessary, such as when the appointment time is close, and the user is not around the appointed vicinity [22].

In this work we present an application of indoor positioning in an application with location-aware push notification requirement, deployed in our campus at Universitas Multimedia Nusantara, Indonesia. The system itself is still at an early stage, with its initial deployment covering limited area and users. This work serves to display how we benefit from tailoring certain indoor localization method to fit our use case. Testing of the application use case will be discussed, while the in-depth accuracy test of the positioning itself is yet to be performed and shall be done as this work progress. The rest of this paper is organized as follows. Section Two discusses various indoor localization approaches. Section Three discusses about location-based smart notification and its implications on the localization technology we use. The initial implementation and testing of the system are described in Section Four. Lastly, Section Five concludes this paper.

II. Indoor Localization Approaches

In the last two decades, interests towards indoor localization application have sparked numerous works on developing robust and scalable indoor localization system. Those works range widely in terms of the physical / wireless technology being used and the localization / tracking algorithm.

A. *Localization Technology*

As more wireless standards emerge, researchers have been proposing the utilization of those standards for locating objects / people in indoor environment. A single or multiple wireless standard(s) may be utilized by the localization system. Evaluation of those wireless standards are usually based on these several parameters [1], [2]:

1) *Signal Quality and Precision*: As the available wireless standards are designed for different purposes, their signals may have different propagation characteristics which affects range, penetration, and received signal quality. This will affect the required infrastructure particularly the number of transmitters, e.g. access points in Wi-Fi infrastructure. The longer the signal travels and be detected reliably, the less transmitters needed throughout the indoor environment. This however does not directly yield lower deployment cost as the cost of individual transmitter may be greater. Precision of the tracking, i.e. minimum range that can be detected is also affected by the signal characterics of the wireless standards. For example, UWB transmission allows precision up to 15 cm indoor, Wi-Fi at 2-5 m, Bluetooth at 2-3m, etc.

2) *Operating Frequency*: Choosing the existing wireless standards also requires proper consideration of their operating frequency. In general, like many wireless applications, we want the less crowded frequency to reduce the interference. Standards operating at free ISM bands such as Bluetooth, Wi-Fi may have disadvantage on this aspect.

3) *Existing Infrastructure & End-device Support*: As the indoor positioning relies greatly on the anchors, i.e. the transmitters, having the transmitters deployed throughout the indoor environment is crucial. Generally, having more transmitters or anchor points results in better localization, but there is also a possibility that these additional anchor points provide unreliable signal quality hence resulting in worse localization [23]. Availability of end devices also plays an important part in deciding which wireless standards to use, as these devices serve as identifier to the object or people being tracked. For example, while both Wi-Fi Bluetooth enjoy the benefit of ubiquitously embedded in almost all mobile devices, Wi-Fi access points are more commonly found throughout indoor environment compared to the Bluetooth counterpart, i.e. beacons. Likewise, cellular system also enjoys both the wide deployment in infrastructure and mobile devices. However, cellular system in average is less performing compared to Wi-Fi in indoor environment, albeit the limited implementation of indoor cellular transmitter stations (picocells & femtocells).

4) *Power Consumption*: While this aspect applies to both the infrastructure and end-devices, we will keep the discussion to the end-devices part as the infrastructure part is more related to operational cost. During the localization, end device are required to communicate with the anchors periodically. This, depending on the period, frequency of communication, and the baseband signal processing, may affect the power consumption of the end-devices which commonly run on battery. Some wireless standards are inherently low-power, such as Bluetooth Low Energy (BLE), or LoRa [24]. Passive-RFID requires no battery at all on end-devices / tags, but drawn back by the very limited detection range and rather costly readers [1].

B. *Localization Algorithm*

Regardless of the wireless standards or technologies, algorithms being proposed to provide the tracking functionality can be broadly classified into static and dynamic approaches [1], [2].

With static approach, the algorithm is composed of two phases [7], the offline phase (recording) and the online phase (location tracking). The offline phase is where signatures (fingerprint) of the location of interests (which could vary depending on the application) are being recorded and stored in the system database. The signatures being recorded also varies widely depending on the wireless technology being used. One commonly used signature is the received signal strength (RSS) of Wi-Fi access points. Once the offline phase is done, i.e. recorded signatures for every location, the system can be deployed to online phase. Continuing the example of Wi-Fi RSS signature, in online phase the location tracking is performed by having the user end-device reads the RSS it is receiving and compares it to the signatures database. The comparison then may determine whether the user is in any of the recorded location, or in between. The simplest comparison function is Euclidean Distance function [7]. This approach provides good accuracy if the offline process is performed properly. However, it is disadvantaged since the offline process is tedious to perform both initially and during maintenance. For example, Wi-Fi infrastructure may change due to broken down access points, or just topology changes. Such approach may require additional cooperation with the network manager to avoid tracking malfunction.

With dynamic approach, the system determines user's location directly by estimating distance to the known anchor points based on the received signals. The estimation is commonly performed with triangulation, which is very similar to outdoor positioning system such as GPS. Metrics being used in the triangulation may vary from time-of-arrival (ToA), time-difference-of-arrival (TDoA), signal strength (RSS), time-of-arrival (ToF), etc [1], [4]. This approach is similar to the static approach in terms of its reliance on the anchor points, that is requiring them to be non-changing over extended period of time else re-adjustment is needed. However, there is no initial work involved as in creating the signatures (fingerprints).

Both methods however do not define where to implement the calculation, i.e. on the server side or client side. In the case of server-side calculation, user end-devices will have longer battery life, but there will be delay as the signal measurements need to be sent over to server and back to the end-device after calculation. Moreover, that process may need additional internet connection to the server. On the contrary, putting the computation on the client side will increase the end-devices power consumption (depending on the computation complexity).

III. Notification and the Indoor Localization Requirements

A. *Smart Notification System*

As described in [21], interruption overload generated by push notifications from computer system, e.g. smartphones may lead to decline of user's productivity. Take for an example a campus with mobile application where students and lecturers can be notified of the upcoming classes, or where lecturers and staffs are notified of their meeting appointments. Such notification system would only serve its positive purposes up to a certain point in which people can still handle the amount of information presented. A more context-aware system does not notify users if they are already in the designated class or meeting room. This work assumes the use case of a mobile application with location-based smart notification [22], in which user can schedule meetings, book the available meeting rooms, and get notified accordingly (based on current time and user's location). The indoor localization requirement for this use case will be detailed in the next subsection.

B. *Location-based Notification Localization Requirements*

Considering the use case assumed in this work, the positioning system has no necessity to track people's exact location all the time. First, the positioning system is only necessary near the appointed time (it is set to T-15 minutes in this work). Second, in its most basic form, the position tracking only needs to determine whether user's location is in the vicinity of interest or not. Hence, the fingerprinting method would fit this scenario well. We benefit from the accuracy of offline fingerprint recording while reducing the number of fingerprinted locations or rooms to a manageable number.

Tracking people's exact location throughout the building indeed provides additional functionalities such as calculating user distance to the vicinity and informing when should the user leave for the meeting. However, this approach comes with trade-offs in immense offline fingerprinting work (and its maintenance) and possibly larger power consumption in user's mobile devices due to the extra computations required. To limit the scope of the trade-offs however, we shall keep the power consumption factor out of this work.

The wireless infrastructure used in this work is Wi-Fi as it is already deployed campus wide. With the limited amount of locations or rooms to be recorded, deploying Bluetooth beacons to those places would be feasible too with little cost for the beacon devices. However, should the system be expanded to cover wider area and possibly the whole campus, the additional cost of Bluetooth beacons could add up to a hefty sum.

C. Localization Technique Design

In general, our Wi-Fi indoor localization system is comprised of two parts, the offline fingerprint recording and the online user location tracking. An Android mobile application is developed for the offline fingerprint recording purpose. Result of the fingerprinting process is saved in a JSON-formatted file and passed to the user-side mobile application. The user application is a meeting room booking system [22] with location-based push notification, which uses the recorded fingerprints to determine whether the user is in the appointed room or not.

Fingerprint recording with the utility application is performed in these several steps below. The application's front page is show in Figure 1.

1) Pressing the '**Scan Wi-Fi**' button will scan the surrounding Wi-Fi for the campus wide deployed Wi-Fi SSID, which in this case is 'UMN'. This should return list of access points (AP) along with their MAC address and received signal strength (RSS). The MAC address is greyed out in this paper for security reason.

2) The APs list is automatically sorted by RSS. The application increments the '**Scans saved**' counter by one, informing how many scans performed that yet to be saved.

3) Process one and two may be repeated for multiple times. The application automatically records each scan and averages the RSS of each APs accordingly.

4) Pressing the '**Save FP**' button will lead to the fingerprint creation page, shown in Figure 2. Here, the application displays the top four APs by RSS. We can specify the virtual coordinate and name for the location being fingerprinted and save it to a JSON file. Here, both the virtual coordinate and name field may represent the location index in the system. By default, the newly fingerprinted location will be appended to the existing list in the JSON file, if any. Checking the '**Clear existing Fingerprint database**' box will clear the JSON file and remove all existing fingerprints. **Error! Reference source not found.** shows the JSON file format.

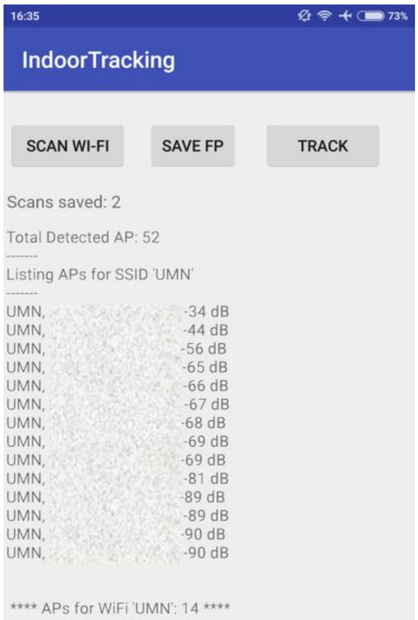

Fig. 1. Fingerprint Application Front Page

In this work, the name field is used instead of virtual coordinate for indexing different locations. Since the indoor localization is used in a meeting room booking application, the location of interest would be meeting rooms. The fingerprint collection for each room is performed in the middle of the room, by scanning APs for five successive times before saving it to the JSON file. The resulting JSON file is stored locally in the device storage and used by the user-side meeting room application.

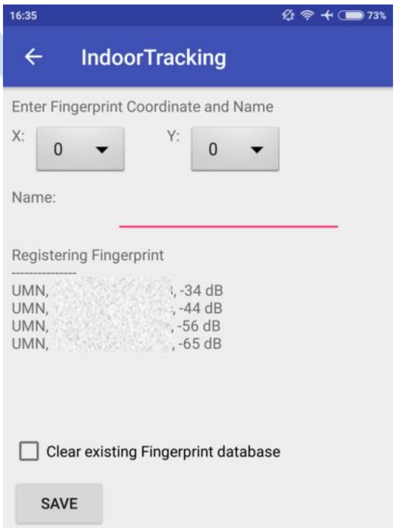

Fig. 2. Fingerprint Application Creation Page

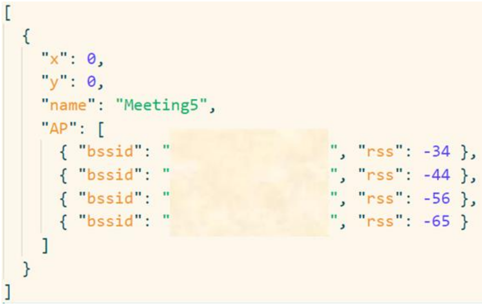

Fig. 3. JSON File for Fingerprint Database

The user-side application contains a background logic for push notification that will start 15 minutes before the appointed time. Once the logic starts, the application scans the surrounding for Wi-Fi networks broadcasted with SSID of 'UMN' along with the APs MAC address and RSS. Note that the user-side application only requires the Wi-Fi to be on, it does not require the device to be connected to the 'UMN' Wi-Fi network. Like the fingerprint recording application, the scan result will be sorted by RSS. The top four APs will then be compared with the previously recorded fingerprints (in JSON file) using Euclidean Distance [7] to determine whether the user is in the room of interest.

That is, we calculate the Euclidean Distance D of the recorded fingerprint (list of Aps and their signal strengths) Rk and the user-side application received signal strengths at certain instance, P. We define R as a vector of fingerprints for each room of interest, with each fingerprint being a vector whose element is an object composed of AP's MAC address and RSS. These are shown in equation (1) and (2), respectively. Similarly, P is a vector of APs and their respective RSS.

$$R = \{Rk\}, k = 1,2, \dots n\ rooms \quad (1)$$

$$Rk = \{\{APj_{mac}, APj_{rss}\}\}, j = 1, \dots, 4 \quad (2)$$

$$D = \sqrt{\sum_{j=1}^{4} (Rk_j - P_j)^2} \quad (3)$$

$$inside(Rk, P) = \begin{cases} 1 \; if \; D(Rk, P) \le t \\ 0 \quad\quad otherwise \end{cases} \quad (4)$$

Room index k will be selected based on the upcoming meeting appointment, assuming a one to one mapping from index k to the room name. User will be deemed to be inside the room if the resulting Euclidean Distance is less than certain threshold value, described in equation (3) and (4), respectively. As this initial implementation is limited to a single meeting room, we took the leverage of hardcoding the threshold value into the application. However, the method that yields the threshold value is reproduceable for any room in future work, i.e. we record the fingerprint values at multiple points around the edge of the room and calculate the average distance from those points to the fingerprint at the room center. The next section details the integration of the indoor positioning into the user-side application.

IV. Initial Implementation and Testing

A. *Meeting Room Booking Application*

In our previous work [22], based on the initial user requirements, we developed a hybrid mobile application using Ionic Framework in which the location-based smart notification system works. User acceptance test shows promising results. Several main findings are that the hybrid application is perceived to be useful and easy to use due to its fast development pace to be deployed into multiple platforms, giving the user more time to experiment with the app and make necessary changes along the way. However, there are still some things to consider when choosing the approach to develop a mobile application, such as performance and user experience [25]. In this paper, we developed a native version of the same application for Android, using its native language, Java. The new native application serves to be a comparison to the previous hybrid application.

As seen in Figure 4, user must have an account to use the application, in this application, we use a free version of Google Firebase's [26] authentication feature for user registration and sign-in method. We then get the ID of each user from Firebase then save the remaining data into our own backend server using PHP and MySQL. After signing in to the application, user will be able to see all the bookings made to the meeting room, including bookings from other users. For bookings which are created by the current user, the user can edit and/or delete them, however, a user cannot edit nor delete bookings made by other users.

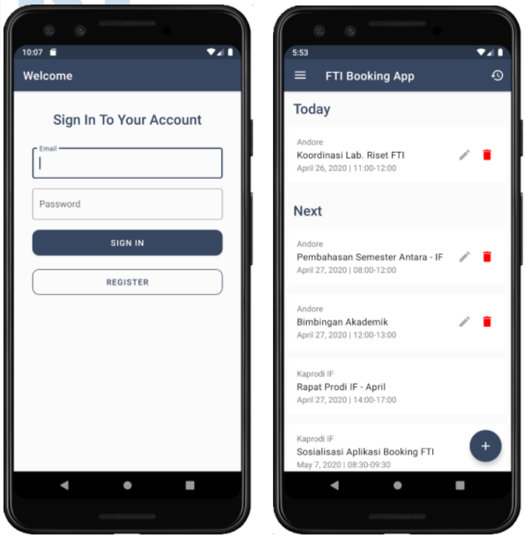

Fig. 4. Sign-in and Main Page User Interface

Our location-based smart notification system will notify users 15 minutes before a booked-meeting starts only if the user is detected as not in the meeting room, as can be seen in the left-side picture on Figure 5. Furthermore, to add a new booking, users can simply click on the floating action button on the bottom right of the main page UI (picture on the right in Figure 4), and the UI as shown in the right-side screen on Figure 5 will be displayed.

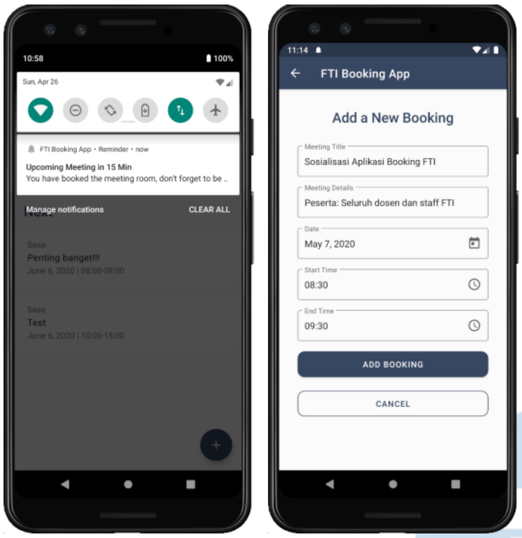

Fig. 5. Meeting Notification and Add New Booking User Interface

B. *Application Testing*

The functionality of the developed native application explained in the previous section has been tested in various scenarios. The detailed scenarios and results can be seen in Table I below.

TABLE I. BLACK BOX TESTING RESULT

Scenario	Result		
	Expected Output	***Actual Output***	***Status***
Register using an existing email account	Invalid email: already existed	Invalid email: already existed	OK
Sign in with invalid data	Can't sign in, invalid email or password	Username or password incorrect	Need fix, not username but email.
Sign in with valid data	All current and future booking data are shown	All current and future booking data are shown, with delete button on user's own bookings	OK
Button click: Floating action buttton (+)	Add new booking page is shown	Add new booking page is shown	OK
Button click: Add New Booking (Start time is after end time)	Invalid start time	Invalid start time	OK
Button click: Delete booking	Booking deleted	Confirmation pop up -> if YES -> Booking deleted	OK
Button click: History Icon	All past bookings are shown	All past bookings are shown	OK
15 minutes before any user's booking time AND user is detected not anywhere near the meeting room	Meeting notification is shown	Meeting notification is shown, however if user's device time is not correct, then it will follow the incorrect time	Need fix
15 minutes before any user's booking time AND user is detected to be in the meeting room	Meeting notification is not shown	Meeting notification is now shown, however, in some occasions the detected location is not precise and the notification is shown	Need improve ment
Button click: Logout	Sign in page is shown	Sign in page is shown	OK

As shown in Table I, most of the functional requirements are met by the newly built native application. However, there are some improvements need to be made, especially concerning the location-based notification. In most cases, in which the device time is correct, and the received Wi-Fi signal is good, there are no problem. However, there are some cases where the location detection is not accurate, and device's time is not showing actual time. We suspect that the intermittent misdetection problem stems from unstable Wi-Fi signals due to interference and/or the device's Wi-Fi receiver quality, and that a more robust fingerprinting method is required. Further testing and evaluation are needed to first measure the accuracy of the indoor positioning system in detecting the users' location. The rigorous evaluation also requires multiple devices involved as wireless receiver embedded in the devices could vary.

On the other hand, based on several quick interviews with the application's potential users, so far, the performance and user experience of both the previous hybrid application and the current native application are nearly identical. However, we considered that in terms of scalability, it still needs more rigorous testing where the number of users accessing the server is increasing rapidly, or tested in various operating system version (various devices with different API level in Android) to be able to be confident that in our case, the hybrid and native application are both nearly identical in terms of performance and user experience.

V. Conclusion

In this work, we presented a Wi-Fi fingerprint-based indoor positioning, applied in a location-aware meeting room booking application. In this initial implementation stage, the native Android application's booking and notification functions properly. Tailored to the application needs, our localization approach reduces the number of fingerprints needed while still functioning well under good Wi-Fi signal condition. Incorrect location detection happens intermittently due to poor Wi-Fi signal condition and/or the quality of the device's wireless receiver.

Future Works

As this work only evaluate the indoor localization functionality in the application, future works should include improving the localization in poor signal condition and conducting thorough testing and evaluation of the localization system performance. Additional features such as punctuality record and Google Calendar integration can also be added to the meeting application.

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