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Dynamic navigation indoor map using Wi-Fi fingerprinting mobile technology

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ABSTRACT

This paper presents the exploitation of Wi-Fi signals sensors using fingerprinting method to capture the location and provide the possible navigation paths. Such approach is practical because current smartphones nowadays are equipped with inertial sensors that can capture the Wi-Fi signals from the Wi-Fi's access points inside the building. From the comparative study conducted, the AnyPlace development tool is used for the development of dynamic navigation indoor map. Its components, namely; Architect, Viewer, Navigator and Logger are used for different specific functions. As a case study, we implement the proposed approach to guide user for navigation in Sunway Pyramid Shopping Mall, Malaysia as floor plan as well as using Google Maps as the base map for prove of concept. From the developer point of view, it is observed that the proposed approach is viable to create a dynamic navigation indoor map provided that the floor plans must be generated first. Such plan should be integrated with the SDK tool to work with the navigation APIs. It is hoped that the proposed work can be extended for more complex indoor map for better implementation.

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1. INTRODUCTION

A map is a graphical representation of geographical structures of an area showing the physical features, such as terrain, topography, landscape, land use, territories, roads, rivers and its catchments as well as country borders [1-2]. Travellers use map as a navigation tool from one point to another and relying on the accurateness of the map to give insights of the unknown territories. The available data gleaned from the map gives extension to the human limited perspective hence it is imperative to keep the map updated and relevant. Traditionally, a physical map is referred when travelling. Travellers need to identify few information, such as; north direction, current position, heading directions, destination, map scale and legend [3]. Some travellers may get frustrated if he/she is not competent of reading the map and may get lost. The intricacy of the information presented on the map making it more difficult as typically the size of the font used is very small and not visual friendly to travellers with hyperopia problem or visually impaired. Moreover, paper-based map is easily folded, torn and get dirty resulting the usage of physical map may not be convenient. Hence, a digital map is a way forward that can provide flexibility, mobility and ease of use.

Map can also access both outdoor and indoor geographical area. With the advancement of Global Positioning System (GPS) technology, map can be dynamically accessed on real time. This is because there are no obstructions to the satellite transmission that allows the GPS unit searches for three or four satellites to lock the current position. However, using the same method for indoor map may posed as a challenge because the GPS signals are attenuated and scattered caused by roofs, walls and other objects and the error range of the GPS chips may be larger than the indoor space itself. Therefore, the localization method using other sensors is needed to build an accurate indoor navigation system.

Smart phone seems to be ubiquitous in our everyday life. It keeps users connected through various communication channels such as messaging services, email, video and audio calls and are equipped with features such as games, music, built-in camera, video, voice recording and playback, Wi-Fi, internet browser, files sharing, Bluetooth, Global Positioning System (GPS) and maps [4]. In addition, the availability of multiple state of the art sensors such as magnetometer, accelerometer, barometer and gyroscope with Wi-Fi technology [5] making the dependability to smartphone to be more demanding. Maps in mobile device helps people to comfortably view the map as user can select the zooming preference. The application can assist user to find the location, tracking the path and calculate the fastest route between two points [6]. User only requires to upload the right map and the other prior information that needed to know, such as; heading directions, arriving time, traffics updates as well as user's current position will be automatically provided by the app. Combining the outdoor and indoor digital maps will allow the user to navigate better and faster. There are several brands of mobile devices have started to support outdoor pedestrian navigation and keep guiding the users when moving in indoor environment [7]. The digital positioning aids for pedestrians were perceived useful only if the provider provided further information or supported more navigation tasks [8].

Finding common amenities such as restroom, parking area, hall, elevator and staircase in a building is important especially if the building is new and unfamiliar [9]. Indoor map covers a closed area in a building which is smaller than the outdoor map [10]. It consists of spaces and areas in the building such as rooms, staircases, elevators, escalators and corridors. User can traverse from multiple room in the same floor or multiple floors within a building. However, in most building in Malaysia, the dynamic indoor map navigation is still scarce and not freely available. In this paper we attempt to develop an interactive mobile indoor map that can help user to navigate inside a building using Wi-Fi fingerprinting technique. This is because interactive maps will help the user to differentiate the spaces and areas inside a building [11]. The scope of this work is focusing on Sunway Pyramid Shopping Mall indoor map due to the availability of its base map and currently there is no indoor map available for the customers.

This paper is organized in the following manner: in Section II, we elucidate the common concepts used for the proposed approach and make a comparative study on the state-of-the-art approaches available on the market. Although it is not exhaustive, the comparison gives us some starting point for the project. In Section III, we presented the methodology used for the project. The developmental phase is discussed in detail. In Section IV, we provide the implemented dynamic navigation indoor map and the findings and analysis before concluding the paper in Section V with conclusion and future work.

2. LITERATURE REVIEW

2.1. Map

A map is a figurative representation of selected characteristics of an area of land or sea showing physical geographical features and usually drawn on a flat surface that represents the information about the world in a simple manner [12]. Maps can show distributions of things over the earth, such as plantations types and patterns [1-2]. Maps can be used for outdoor and indoor. Both maps representing similar features but indoor maps have floor plans that overlay on top of the base map. These floor plans are gathered from building blueprint. The building may comprise of multiple floors and each floor owns its own floor plans [10]. Base map is used to ensure that the foundation of the map is held on a grid. Otherwise, the indoor map will look as if it is floating. Floor plan depicted the different level plan that is created on top of the base map that connect spatial data to physical locations in the building in more detailed manner. Typically, a floor plan consists of location of rooms, amenities, elevators, stairs, escalators and other facilities in the respective building.

2.2. Base map

Base map is used to provide a visual reference and background detail necessary to orient the physical location of the map. Malaysia Geoportal defined base map as a diagrammable data that repeatedly used for locational reference and control [13]. It is used as the fundamental denominator for map scale, coordinate system and projection for other maps. There are several publicly accessible base maps for mobile app such as OpenStreetMap [14], GoogleMaps [6] and HERE maps [15]. Each map has its own characteristics that enable developers to use the base map. OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations and other physical characteristics globally [14]. It practices the open data concept which users are free to use the base map for any purpose and credited OpenStreetMap and its contributors.

Users may distribute the result only under the same license although they alter or build upon the data in certain ways. Google Maps is a web mapping service developed by Google [6]. It offers satellite imagery, street maps, 360° panoramic views of streets (Street View), real-time traffic status (Google Traffic), and route planning for travellers that travelling by foot, car or public transport. In addition, HERE Technologies has created a comprehensive mobility application that can help provide complete transportation options and navigation guidance [15]. Consumers can get instant access to offline maps for more than 110 countries, public transit information for more than 1,300 cities and 3D indoor maps for thousands of shopping malls, airports and sports venues. HERE maps can operate on web, desktop and mobile application. In this work, we apply Google maps as the base map because the location selected which is the Sunway Pyramid Shopping Mall is registered and integrated with Google Map.

2.3. Floor plan

Floor plan need to be prepared a priori to overlaying on top of the base map. Preparation of floor plan can be implemented using digitized or automated approaches. Conventionally, floor plan is prepared using digitization software. Auto computer-aided design (AutoCAD) by Autodesk is one of the famous software for drawing building blueprint [16]. A user is guided to accomplish the analysis, estimates and calculate the construction costs for various types of facilities using the navigation patterns [17]. In addition, AutoCAD enables user to plan, estimate and design the layout of a building to create the floor plan.

The contribution of public in digitizing the layout of the floor plan using mobile devices is also one of the approaches that has been successfully implemented currently. The usage of software such as CrowdInside [18] and Magicplan [19] using mobile technology inspire more researchers and developers to generate floor plan. CrowdInside is a crowdsourcing based system for automatic construction of building floor plans [18]. It leverages the smartphones sensors that are ubiquitously available with human and build automatically and transparently construct accurate motion traces. The software can detect the points of interest accurately with 0.2% false positive rate, 1.3% false negative rate and reduce the errors in the inertial motion traces by using elevators and stairs for error resetting [18]. Moreover, another mobile application called Magicplan allows user to create his/her own layout of the floor plan using the concept of Do-It-Yourself (DIY) [19]. It is using the Augmented Reality (AR) technology to capture the corners of the room with an accuracy of 95% and with this software user can estimate the materials needed in furnishing the room.

The design patterns of outdoor maps and indoor map is different. Puikkonen et al. [20] suggested that the following issues, namely; vertical navigation, orientation and relative positioning, navigation by visible landmarks and consistency between the user interface and real world should be addressed when designing indoor navigation maps and user interface. Moreover, using a less detailed map e.g. columns, strange corners and arches could make the orientation easier. The materials, colours and shapes of the environment vary from building to building thus, the consistency between the real and digital presentation need to be paid more attention when designing the indoor maps [20].

2.4. Floor plan localization

The localization method is the core component of an accurate indoor navigation system. There are several numbers of approach methods that can be used for localization in a closed environment and it can be categorized into three categories, namely; lateration, fingerprinting and dead reckoning [21]. Lateration or angulation techniques estimate an absolute or relative position of an object by measurement of distances from multiple reference points using geometry [22]. The distance of multiple reference points which known as beacons to the reference point position are measured. These distances can be provided by such signal measurement information like a received signal strength (RSS), the time of arrival of radio signals from transmitters (TOA), the time difference of arrival of several radio signals (TDOA), the time-of-flight of the signal traveling from the transmitter to receiver (RTOF), the received signal phase (POA) [23]. The accuracy of the distance measurement directly influences the localization accuracy.

The second technique to localize the floor plan is by using fingerprinting approach. This technique collects the signal strength of the Wi-Fi access point (AP)s in the local surrounding at various points in a covered area. Prior to the positioning of the reference point, a database that consists of AP signal strengths values and coordinate of reference point need to be created. The position estimation can be measured by searching matches in the database to the receiver using search/matching algorithm [24]. The localization accuracy is dependent on the adequate number of access point installed in the area. The example of Wi-Fi fingerprinting implementation is presented by Han et al. [25]. The accuracy of the area with weak Wi-Fi signals was always worse than the areas with strong Wi-Fi signals. Fingerprinting using the radio signal or Receives Signal Strength (RSS) is also available. The RSS fingerprinting adapts the Received Signal Strength Indicator (RSSI) which is the radio signal that can be translated into distance from beacon points [26]. The two main approaches for the estimation of locations that using the RSSI values are the pre-recorded radio map of the area of interest is leveraged to infer locations through best matching and the RSSI values are used to calculate distances through the computation of the path loss.

Subsequently, the dead reckoning approach is based on detecting steps and step heading and integration over them in estimating the current user position. It adapts filters and activity-based map matching e.g. resetting the user position to the nearest elevator if elevator like pattern is detected which is similar approach as Alzantot & Youssef [18]. However, Link et al. approach can reset errors by matching the steps using sequence alignment [21]. Thereby, it can reduce errors from turns that is commonly found in indoor environments.

2.5. Comparative study of on the shelf mobile navigation applications

Different available developmental tools are compared in Table 1 to give some head start that can be considered for the development of the project. It is observed that each application is using their customized development tools that may consists generic APIs or custom-made libraries. Most of the tools are using Google Maps as the base map since most users are very familiar with the interface, thematic colours and map functions. Different floor plans as well as the floor plan localization methods for each application are used due to its different purpose.

In this project we apply the AnyPlace development tools for the development of the mobile application, Google Maps as the base map and specifically focuses on Sunway Pyramid Shopping Mall as floor plans. Sunway Pyramid is selected because this building has been registered and integrated with Google Map hence it simplifies the connectivity issue. In addition, the localization technique of Wi-Fi fingerprinting is selected because the building is equipped with Wi-Fi beacons. It is also noted that although the development of an extensive reference point area makes fingerprinting is time and labour intensive, it is extensively adopted because of its high degree of accuracy [22].

3. RESEARCH METHOD

The work in this study adopt the Xamarin Mobile Application Development Life Cycle (MADLC) that consists 5 phases, namely; inception, design, development, stabilization and deployment [27]. Inception phase is the initial stage where the application idea will be outlined and polished depending on the suitability of the users' needs. Questions like is there any similar applications in the market, how this application different from others, what value does this application bring to the user, how will the user use it, is this application responsive when considering the form factor and how to incorporate mobile technologies in the application should be considered. The comparative study to identify the strengths and disadvantages of the available system is conducted to help us to get some insight of the state-of-the-art approaches. In this work, we are employing the AnyPlace development tool with Google Map as the base map and Wi-Fi fingerprinting as the indoor localization method.

Then, the design and development phases are conducted using AnyPlace Architect that combines designing elements with development processes. The base map needs to be prepared a priori to indoor map overlaying process. This is done by using the 'Add Building' toolbox. It needs to be set as public to make it available in AnyPlace Navigator. Then, the building information need to be filled up. The 'Floor' toolbox is used to add the floor plan and the 'POI toolbox' is to provide the floor map with the point of interest (POI)s and edges information. The database for the WiFi signal strength are later created by collecting the data using 'AnyPlace Logger' tool. The results of the data capturing process is the RSS log files that contains the timestamp, latitude, longitude, heading, MAC address of AP, RSS, floor level and BUID. It contains 222,878 records including headers for both G and F floor. However, the logger duplicated the data if we are walking at a low pace, thus the duplication data are removed to 34,841 and 27,127 records for G and F floor respectively. The Wi-Fi fingerprinting map then can be generated based on the latitude and longitude information. The stabilization is the phase during the MADLC to test the application and to ensure it is stable and usable. In this phase, we do the manual testing by walking around the building to verify the suggestion of the application. This project is completed in the deployment phase once the navigation functionality has been tested.

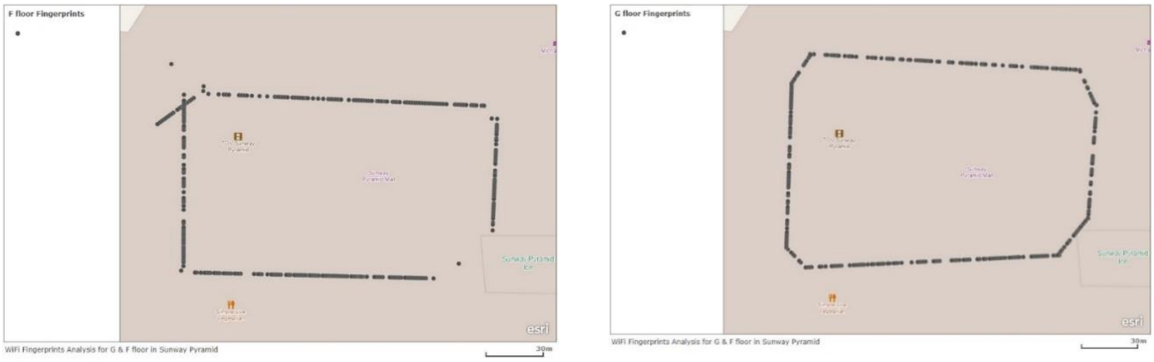
Table 1. Comparative table of similar mobile navigation applications.

App Name	Development Tools	Base Map	Floor Plan	Localization Methods	Project Brief
Anyplace [28]	https://ap.cs.ucy.ac.cy/	Google Maps	Crowd sourcing	Fingerprinting (Wi-Fi)	AnyPlace is an Indoor Information Service (IIS) that adopt an open, modular, extensible and scalable architecture. It consists of 3 interfaces i.e. Architect: To place the floor plans, adding Point Of Interests (POI) and creating the paths; Developer: To deploy and test the end point; Viewer: The searching and navigation for web application. For android mobile user, they can download the Navigator & Logger App in the Google Play store.
FootPath [21]	https://github.com/COMSYS/FootPath	Open Street Map	OpenStreetMap	Dead Reckoning (Accelerometer & Magnetometer)	FootPath is a self-contained and map-based indoor navigation system. It is using the inertial sensors in the smartphone i.e. accelerometer that can be used as a pedometer and magnetometer that can be used as a compass in heading direction. The app works in 2 parts i.e. First: Using the dead reckoning approach in step detection and step heading estimation; Second: Match the detected steps in the specified route from source to destination using sequence alignment algorithms.
Google Maps with Indoor Navigation [26]	Google Maps API	Google Maps	F-block, PESIT, PES University, Bangalore	Fingerprinting (RSS)	This app leverages the RSS information from the Wi-Fi beacons that have been deployed within the buildings. The building elements i.e. rooms, corridors, stairs are considered as nodes (source or destination). The edges are link between the different nodes and Dijkstra's algorithm being used for providing shortest path between the nodes. The algorithm drawn the edges and sends the shortest path to the user.
Kamppi Indoor Positioning Mobile Service [0]	Nokia indoor navigation system	-	Kamppi Shopping Mall	Lateration (Wi-Fi)	This app is a research project that combined indoor positioning, social networking and advertisement. It provides services for location-awareness to the user.
Xamarin [27]	Xamarin.Forms.GoogleMaps	Google Maps	Google indoor maps	– GPS (outdoor) – Device inertial sensors (indoor)	Xamarin is a Microsoft product that can help developer to build Android, iOS & Mac app using C# and . NET in Visual Studio on Windows and macOS. Besides build for single-platform, Xamarin also support build cross-platform for Android & iOS using Xamarin.Forms. Developers have created maps library for Xamarin.Forms that optimized Google maps. The usage is almost as the same with Xamarin.Forms.Maps but it provides maximum Google maps features for Xamarin.Forms.
Micello [15]	Maps SDK & Data API	HERE Maps	HERE indoor maps	– GPS (outdoor) – Device inertial sensors (indoor)	Micello is developed by HERE technologies. The Maps SDK is a lightweight JavaScript library for mobile and web interactive indoor maps. The Data APIs enable to access floor plan in any format. It works across all major desktop and mobile platforms. It was design for user to have control over Maps Data for advanced integrations. All venue maps are hosted in their Maps File Server.
MapsIndoors [29]	MapsIndoors SDK & Google Maps API	Google Maps	Google indoor maps	– GPS (outdoor) – Device inertial sensors (indoor)	MapsIndoors by MapsPeople are used to build the indoor navigation solution. It is built on Google maps and all functionality and design of Google maps is brought in the platform. It can be integrated into existing application for mobile and desktop.

4. RESULTS AND ANALYSIS

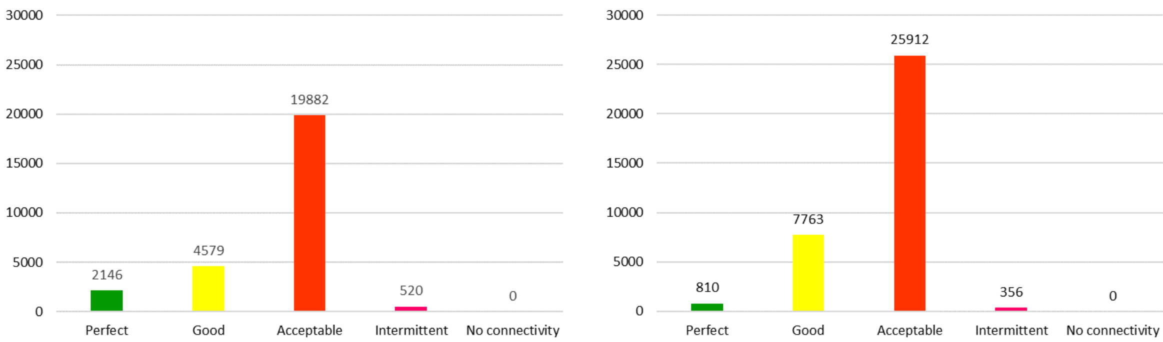
We test the proposed system to see whether the implementation of indoor map is feasible for Sunway Pyramid Shopping mall. Figure 1(a) and 1(b) illustrate the Wi-Fi Fingerprinting map for G and F floor respectively. Figure 2(a) and 2(b) show that both floors have acceptable coverage of approximately 75% followed by good coverage ranging from 16.88% for F floor and 22.28% for G floor. Both floors do not have no connectivity to Wi-Fi making the navigation quite smooth and reliable. Table 2 summarizes the legends in Figure 2(a) and 2(b).

The experimental result shows potential of identifying the connectivity in indoor location and managed to yield comparable result. In both floors, the internet connectivity through Wi-Fi is detectable that almost 75% internet connectivity are in the range of 'Acceptable'. Subsequently, the proposed method can be extended with job seeker applications [30] that illustrate the location of the job to facilitate job searching [31] as well as student profiling [32].



(a) (b)

Figure 1. Fingerprinting map for different floors in sunway pyramid, (a) F Floor and, (b) G Floor



(a) (b)

Figure 2. Different floors Wi-Fi signal intensity, (a) F Floor and, (b) G Floor

Table 2. Summary of the WiFi Signals Intensity Measure

Colour	Indicator	dBm Range	Remarks
	Perfect	0 to -60	Excellent connectivity at the highest speeds.
	Good	-61 to -70	Good connectivity to the Wi-Fi but not always at the highest speeds.
	Acceptable	-71 to -90	Fine connectivity to the Wi-Fi and acceptable occasional interruptions.
	Intermittent	-91 to -100	Flaky connectivity, slow transfer rates and performance issues with multimedia content.
	No-connectivity	-101 to -110	Expect no connectivity to the Wi-Fi

5. CONCLUSION

In this work the Xamarin Mobile application development life cycle (MADLC) were adopted, employing the AnyPlace development tool with Google map as the base map and Wi-Fi fingerprinting as the indoor localization sensor. In addition, the Anyplace architect was used in the design and development phase. The rest of the base map, indoor map, floor plan and the Wi-Fi fingerprinting map needs to be generated first to ensure proper working of the mobile indoor navigation app. The mobile app was tested on the G and F floor of the Sunway Pyramid Shopping Mall, Kuala Lumpur, Malaysia and shown the potential of using such mobile app even when the Wi-Fi coverage is only acceptable. To ensure the correct position of the user in the indoor map the floor plan must be accurately overlaid on top of the base map. Most smartphones today makes use of the GPS and Wi-Fi coverage to locate the user position indoor thus having a strong Wi-Fi signal should provide better coverage and accuracy of the mobile navigation application.

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