GoMap: Combining step counting technique with augmented reality for a mobile-based indoor map locator

Nursyahirah Atikah Sharin, Noris Mohd Norowi, Lili Nurliyana Abdullah, Ng Seng-Beng
Department of Multimedia, Faculty of Computer Science and Information Technology, Universiti Putra Malaysia (UPM), Serdang, Malaysia

Article Info

Article history:

Received Jul 31, 2021
Revised Oct 27, 2022
Accepted Nov 17, 2022

Keywords:

Augmented reality
GoMap
Indoor map locator
Mobile devices
Step counting techniques

ABSTRACT

In recent years, indoor navigation and localization has become a popular alternative to paper-based maps. However, the most popular navigation approach of using the global positioning satellite (GPS) does not work well indoors and the majority of current approaches designed for indoor navigation does not provide realistic solutions to key challenges, including implementation cost, accuracy, longer computation processes, and practicality. The step count method was proposed to solve these issues. This paper introduces GoMap: a mobile-based indoor locator map application, which combines the step counting technique and augmented reality (AR). The design and architecture of GoMap is described in this paper. Two small-scale studies were conducted to demonstrate the performance of GoMap. The first study found that GoMap's performance and accuracy was comparable to other step counting app such as "Google Fit". The second part of the study demonstrated the feasibility of the application when used in a real-world setting. The findings from the studies show that GoMap is a promising application that can help the indoor navigation process.

Corresponding Author:

Noris Mohd Norowi
Department of Multimedia, Faculty of Computer Science and Information Technology
Universiti Putra Malaysia (UPM)
Serdang, Selangor, Malaysia
Email: noris@upm.edu.my

1. INTRODUCTION

It is common for people to face challenges when arriving at unfamiliar places, including locating rooms or venues in an unfamiliar building. Indoor venues inside of buildings are particularly trickier to navigate as the building may cover large areas of similar looking long corridors. Buildings also typically have different floors as well, which requires a different approach to navigation that outdoor approaches.

The invention of global positioning satellite (GPS) advancements made it simpler to progress through real-time information [1], [2]. Several technologies, such as Google Maps and Waze, assist people in finding the shortest route and avoiding traffic jams, saving time and money in the most efficient way possible on mobile and the web. However, because these technologies rely on GPS, they are not suited for locating rooms within a building and functioning better outside, where the signals are clearer and stronger and not blocked by any buildings or walls. Figure 1 shows an example of how GPS fails to show direction once indoor. Printed maps and signage are typically put throughout the building in a variety of locations. The difficulty with paper-based maps is that they often contain out-of-date information and are frequently given in short abbreviations, making it difficult for newcomers to interpret and follow the map as shown in Figure 2.

Figure 1. Example of Google Maps searched from inside a building

Figure 2. Example of paper-based map in a building

Indoor map locator application would be an alternative solution to this problem to replace the current paper-based map inside a building. Indoor map locator is likely one of the most important forms of location navigation solutions available today. In buildings, it enhances guest experiences, offering valuable location services. Indoor map locator or indoor positioning, can be defined as its name indicates, as a mechanism that allows us to position objects and people in closed environments. In other words, it allows sensors or mobile devices to be tracked in an internal environment. With the increasing popularity of mobile devices such as smart-phones and various wearable devices equipped with built-in sensors (e.g. accelerometer, pedometer, and gyroscope), along with step-counting algorithms for walking detection, various applications can be developed for physical exercise, health-care, and location-based services (LBS) [3]-[10]. Step counting is closely related to a variety of applications, including motion monitoring, behavior recognition, indoor positioning, and navigation, in addition to being a key component of pedometers which serves as a fundamental service on smart-phones as shown in Figure 3.

By implementing an indoor map locator, this allows visitors to seamlessly navigate the building campus and find the exact locations of the venues they are searching for. This saves time from wandering around the corridors and reduces the stress and frustrated experienced when feeling lost [11]. In addition to this, those with disabilities who need accessible routes are able to avoid stairs, and instead, be guided towards elevators and wheelchair ramps. Having a clear plan of how to get to the venues can help reduce the feeling of overwhelmed and ultimately create a more positive experience. There are numerous approaches which have been done from previous researchers in order to tackle indoor map locator problem such as using paper-based marker, beacon devices, building information modeling (BIM) tracker, and augmented reality (AR). However, there are still some problem areas open for challenges.

This work aims to improve user experience in finding places, improve productivity, and accessibility indoor by providing mobile application that will include indoor map locator which uses step count algorithm and AR that act as an indoor navigator for users. This paper is organized as follows: Section 2 presents past work relating to indoor map locator and step counting techniques. Section 3 describes GoMap's design and architecture. Section 4 presents the experimental setup in testing out GoMap's performance. The results and discussion are in section 5. Finally, section 6 presents the conclusions and limitations of GoMap.

Figure 3. Example of pedometer application on mobile phone

2. RELATED WORK

While navigation systems and mobile application for outdoor environments are readily accessible, navigation inside particular ranges still poses a challenge. The main reason for this lies in the difficulty to obtain the information of a specific location with main infrastructure and to develop indoor maps. The definition of a location is a specific place or area where something happens or where something takes place. The map is designed for clear access to the location. Locator map, on the other hand, –is a map to show the location of a particular place, which can be used as visual aids when finding places.

It is difficult to locate objects in indoor environments using GPS because indoor GPS signals are weak or inaccessible. Thus, indoor positioning scheme has been researched extensively in recent years. There are several techniques to implement indoor positioning, such as wireless signal, optical signal, or ultrasonic signal receiving techniques. However, these techniques require the signal to be transmitted or received through various access points (APs), which are then used to calculate the user's coordinates [12]-[14]. As many APs are required to be installed throughout the building in order for this method to work, it is a costly solution.

Other methods developed for indoor navigation systems include a system by Khan *et al.* [15], which proposed a navigation system that uses simple fiducial markers with automatic path generation. When each marker is detected and recognized, an audio or textual user guidance pops up on screen to guide users with navigation around the building. In order for the system to work, all the markers needed to be printed, and placed on the ceilings throughout the building such as on the ceilings of offices and corridors. Nevertheless, under ill-lighted environment, the application may fail to detect the markers.

Another possible solution to indoor navigation is through the usage of beacon devices. Koyun and Cankaya [16] proposed a system that implemented Beacon devices function with bluetooth low energy (BLE) communication protocol. However, this solution required beacon verification in order for its pedometer algorithm to function accurately. Huang *et al.* [17] also proposed a system called ARBIN - augmented reality-based navigation system. The LBeacons shares its coordinate information to any available smartphone users in that area of the building, and then navigational instructions are displayed on the screen, integrating it with the real-world environment.

Stationary cameras can function as a more accurate external sensors to help indoor navigation. However, the cameras are expensive, requires manual installation and must be maintained. Herbers and König [18] approached the localization problem with a floor-plan matching algorithm through template matching with an indoor localization for augmented reality devices using BIM. Acharya *et al.* [19] proposed a visual indoor localization approach by utilizing mobile devices with cameras and 3D building models of buildings. The system compared the images captured by the smartphone camera with the data set corridors in the building.

Alternatively, an indoor navigation system can be combined with augmented reality technology in order to help indoor navigation. Yao *et al.* [20] proposed an augmented reality indoor navigation system that can quickly search for the shortest path to the destination and with the improved navigation algorithm. However, one of its setbacks was motion blur due to jerky camera motion which blurred the edges and made it difficult to perform continuous tracking.

The step count information is used to develop various smart-phone services technology and nowadays, it is used to aid human's life through many applications. Some examples are such as utilizing users' trajectories to assist wireless fingerprint indoor positioning functions [21]-[23]. This method uses the user's walking direction and distance to determine the trajectory, where the step count is used to estimate the distance. Other example of step count method uses is in in managing and keeping track of healthy lifestyle, such as recording the number of steps that a user has walked in a day [24]-[26]. Once the user's habits are recorded, these applications will be able to provide some health tips for the user to manage their lifestyle better. This can be extended to designing exergames, where it can help motivate users to do the exercise more consistently [27].

There are multiple AR-enabled mobile applications that attempt to assist users and improve their user experience in terms of location and direction, as they have different needs and expectations when it comes to access information. The use of AR as the basis of the idea was highlighted in tourist guide mobile applications, for example. Mobile applications that offer access to tourist hot-spots places, retail information, museum experiences, and booklets, as well as exchanging information about new and remarkable destinations, have been developed in several of the adopted systems [28]-[31]. The use of outdoor interfaces to produce animations or useful texts with the ultimate goal of giving tourist aid, specifically in the Antarctica was also proposed in [32]. In addition, augmented reality was used to integrate interactive technologies for museum displays in [33]. Four applications had a lot in common, including the use of a mobile device because one of them had an AR feature and offered map module [28], [33]-[35]. Internet access was required to post information such as pictures, notes, and the name of the current visited location, as well as to access various online services.

Traditionally, physical indicators, resources, and human guides have all been used in the past to determine the position and direction of the surrounding areas. However, this method is not always acceptable for the needs of a user in a huge, unfamiliar environment. The use of a step count algorithm combined with AR technologies seems a promising solution to indoor navigation, which will be explored further in this paper.

3. IMPLEMENTATION OF GoMAP

GoMap is a mobile application which include a section focusing on the inside building and use an AR feature to show the directions when user enter a building. In addition, the application should include information about the room, such as where it was located, which floor and block it was on, room availability for booking purposes and the information of the person in charge of the booking room system. As well as the structure of the building from the outside before entering the building to find a room.

GoMap's general mechanism is divided into two parts: i) step counting algorithm; and ii) AR detection. The step count algorithm counts the number of steps the user needed to take before prompting the user to start scanning some markers. Once user's step count algorithm is activated, the AR detection starts. User scans around the surrounding environment in the building, and certain angles and shots in the building are made as marker. The markers, in return, confirm the locations of users which is estimated using step counts that are converted into distances. The markers also prompt the display of the arrows on the mobile phone's screen, The arrows act as guides to visually direct users to their intended destination.

Figure 4 in the following page depicts the application flowchart of GoMap. When users first use the app, they must type keywords into the search field to acquire a list of similar keywords. Users may select the room's name and a 3D map will pop up to display the floor layout in order to reach the room. From the starting point, users need to use the GoMap app on the phone and slowly scan the surrounding environment. The 'environment' captured on the camera acts as a marker and can thus detect the location and suggests the right route to take with arrows displayed on the screen of the mobile phone as shown in Figure 5. The act of walking will activate the step counting process as shown in Figure 6, which will be used as a guide to the distance from the starting point to the location. At every turn or intersection, a prompt will be displayed on screen, asking users to scan the environment again, and the distance from the updated location to the intended venue is continued to be calculated. This AR scanning of the environments can happen several times across the facility until the venue is reached.

In Figure 7 shows the architecture for GoMap, which is inspired by the proposed application by Fabricio *et al.* [36]. The architecture depicts the most important activities that users may take when using the application with AR resources. When using the GoMap, users will use real-world objects inside the building as AR markers. The usual method of establishing AR is for a mobile camera to detect markers and deliver information related with those markers; in this scenario, users may see an arrow pointing in the right direction on their mobile devices to help them get to their destination. This navigation form is built with AR markers that use real objects inside the building, which consists of the application's ability to perceive the real environment in which the user is in, using the mobile device's camera, gyroscope, and accelerometer to present virtual elements that are integrated into the actual environment. The concept is very similar to making movements in the VR environment, such as in [37].

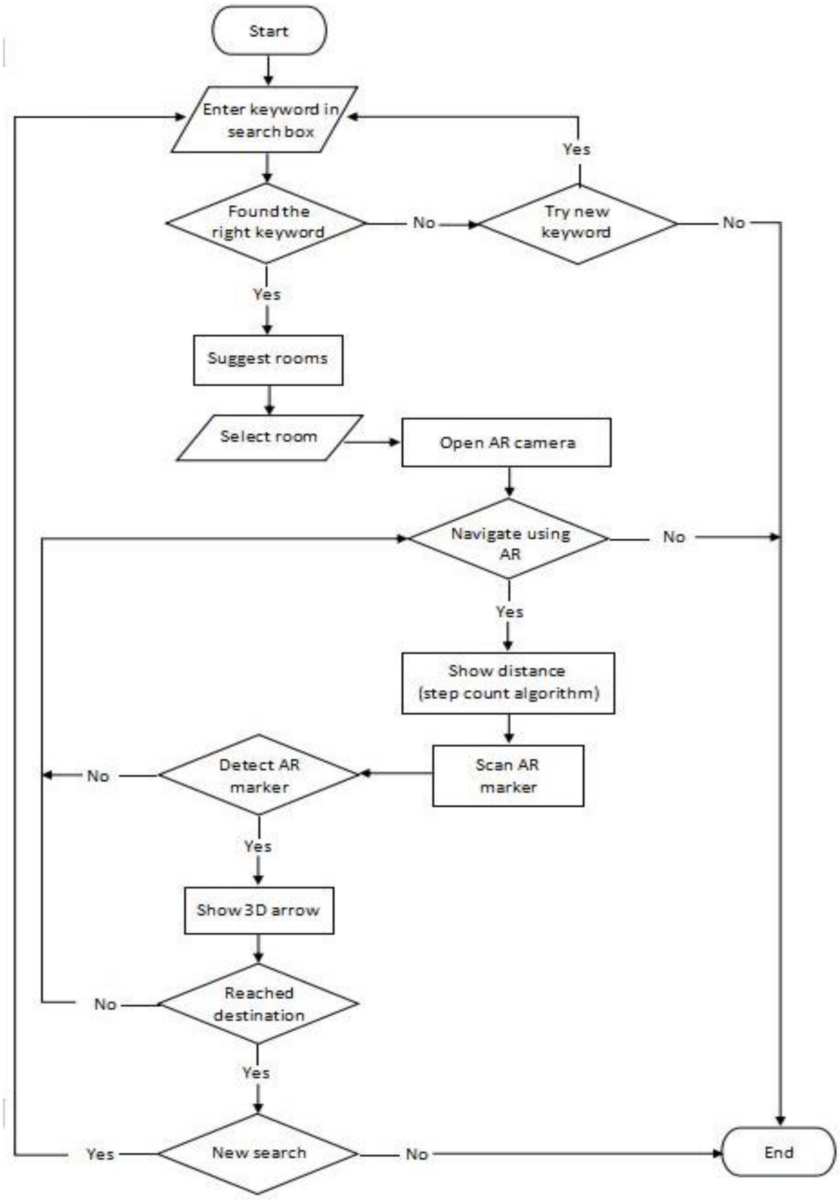

Figure 4. Flowchart of GoMap

Figure 5. The AR view from real world environment. Once the environment is detected as a marker, an arrow is displayed showing the next immediate turn to take

Figure 6. The interface of step count part

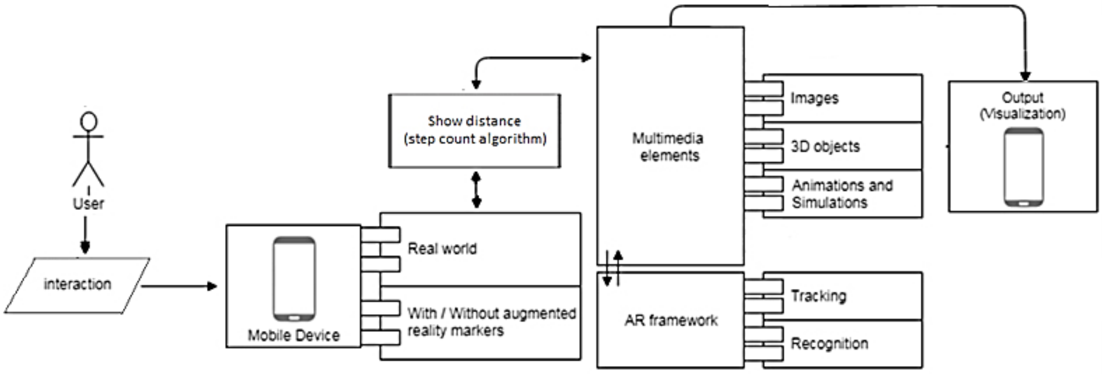

Figure 7. The architecture for GoMap application

4. EXPERIMENTAL SETUP

In order to demonstrate the performance of the GoMap app, two small-scaled studies have been designed. The first study compared GoMap's step counting accuracy against manual step counting and also against another step counting app (Google Fit). This was done to validate GoMap's performance–whether it was comparable to other accepted methods of estimating the distances walked by users, by translating the number of steps into distances.

The second study was designed to demonstrate the feasibility of GoMap when used in a real-world setting. In the second study, two sets of participants were also involved and were given the task of searching for the correct pre-set venue. One group of users searched for the venue using GoMap, while the other group only used a paper map. The time it took for the venue to be discovered (efficiency), as well as the distance between participants' end location, the pre-set location was also compared (accuracy).

4.1. Study 1: accuracy of GoMap

Fifteen users (six males, nine females), aged between 26-60 years old, with a height of with height 150 cm and above, participated in this study. The study was held in the hallways at the top floor of Block A, Faculty of Computer Science and Information Technology, Universiti Putra Malaysia (FCSIT) as shown in Figure 8. Three straight-lined paths with difference distances were selected and marked, i.e. Path A=8.9 meters; Path B=11.2 meters; and Path C=16.4 meters respectively as shown in Figure 9. The measurements for all three paths were pre-measured using a construction grade measuring tape.

Participants were asked to navigate through the three paths, and were provided with two mobile phones of the same model–one installed with Google Fit and the other with GoMap apps installed. The participants had to walk the entire marked length of each path with one mobile phone in each hand, where the number of steps would be recorded on the app. They also had to loudly do a manual count of the number of steps taken from start to finish. Participants had to repeatedly walk each path three times, as three readings were recorded per path. The average number of steps per path obtained through the Google Fit's reading, the GoMap reading, and the manual reading were then calculated. The study was conducted face-to-face, amidst a national lockdown in Malaysia due to COVID-19, which contributed to the slightly small number of participants in the study. However, with this small sample size, it can be seen that GoMap has managed to estimate distances comparably well compared to another step counting app, which is discussed in the following section.

Figure 8. The hallway at the top floor of Block A, FCSIT UPM, where study 1 was conducted

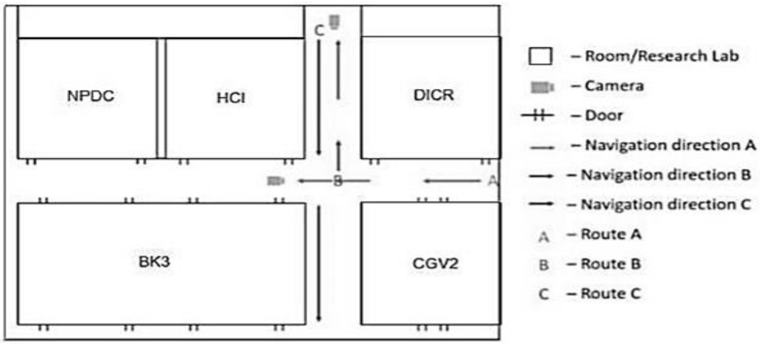

Figure 9. The layout of the three paths in the study (Path A=8.9 meters; Path B=11.2 meters; and Path C=16.4 meters)

4.2. Study 2: feasibility of GoMap

Four participants (3 male, 1 female), aged between 25-60 years old, were involved in this study. The study took place on the top floor of the block A building at the FCSIT UPM. The participants were asked to locate an imaginary room called '*Bilik Mawar*'. All participants had the same starting point (X). The location of the room was not disclosed. In reality, there was no room called '*Bilik Mawar'* in FCSIT, UPM, but the room name was created to eliminate biases which might occur from the participants who might be familiar with the layout of the building. The imaginary room, '*Bilik Mawar'* was staged on a room called '*Bilik Kuliah 2*', situated on the corridor of the block A building facing the central parking lot (Y). A signage with '*Bilik Mawar'* was placed on this door during the duration of this study. The layout of the floor as well as the shortest path the participants needed to follow from the starting point to '*Bilik Mawar'* is illustrated in Figure 10.

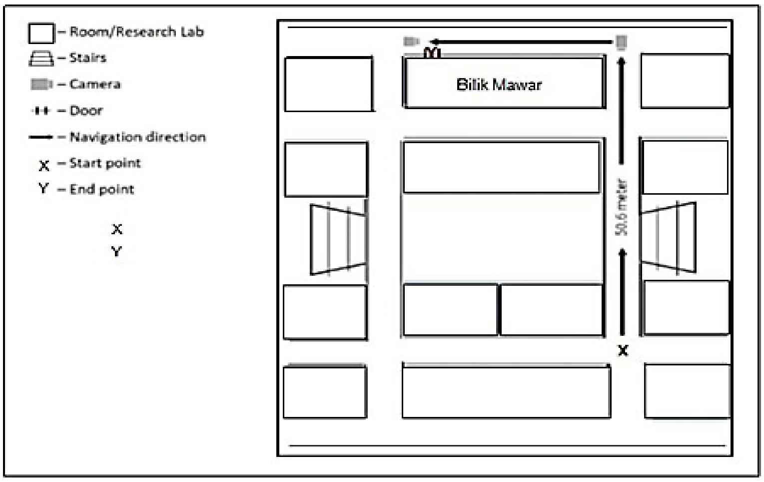

Figure 10. Layout of the floor and the shortest path from X (starting point) to Y (*Bilik Mawar*)

The participants were divided into two groups–with GoMap app, and without GoMap app. No sets of instruction to reach the room was disclosed to either group. The first group (with GoMap app) had to locate the room by following the directions displayed on the screen of the mobile app. The step count method along with the accelerometer embedded in the mobile phone were utilized in the navigation process. The second group (without GoMap app), were provided with a paper map, and had to self-navigate until the room was found. The time taken for the task to be completed were recorded. The performance of both groups with respect to efficiency and accuracy were measured and compared. This is discussed in the Results section which follows.

5. RESULTS AND DISCUSSION

The previous section details the experimental setup of two studies conducted in this work. The first study discussed the accuracy of the GoMap app, while the second study demonstrates the feasibility of the GoMap app in the real-world setting. The results of the two studies are discussed.

5.1. Study 1: accuracy of GoMap

In Table 1 shows the average reading of steps obtained between Path A (distance=8.9 meters), Path B (distance=11.2 meters), and Path C (distance=16.4 meters), across three different step counting methods–via manual counting, via Google Fit app, and via GoMap app, from the fifteen participants who volunteered in this study. In general, it can be seen that manual step counting has the most stable readings between the participants on all three paths, i.e. with a small standard deviation reading ($\sigma<2.0$). This was used as a base reading for the number of steps in the paths. A simple comparison between the readings obtained from the Google Fit app with the GoMap's app reveals that GoMap's readings are closer to the base readings (manual) by +/- 3 steps at most. In comparison, the step readings from the Google Fit app had bigger difference values to the base readings. This means that GoMap has a higher accuracy in step count reading, and it suggests that the algorithm implemented by GoMap app is more refined to suit a human's natural walking pattern. It is worth noting also that GoMap also has a small standard deviation value ($\sigma < 4.5$) between all the readings from the participants. This implies that GoMap has a good reliability in step counting.

Table 1. Comparisons of the step counting accuracy between GoMap and other methods

No.	Analysis	A 8.9 meter			B 11.2 meter			C 16.4 meter		
		Manual	Google Fit	GoMap	Manual	Google Fit	GoMap	Manual	Google Fit	GoMap
1	Mean (μ)	14.7	7.8	12.9	17.7	7.7	17.5	26.4	14.5	23.3
2	Standar Deviation (σ)	0.841	3.081	1.163	1.307	3.940	4.422	1.765	3.700	2.740

5.2. Study 2: feasibility of GoMap

In Table 2 shows the time taken (in minutes) between four participants in locating an undisclosed staged room (*Bilik Mawar*). It can be seen that participants provided with the GoMap app to aid their navigation in finding the room successfully completed the task with an average time of 1 minute and 51 seconds. In comparison, participants who were not provided with the GoMap app took an average time of 8 minutes and 42 seconds to locate the room. This shows that GoMap is not only feasible and fully functioning in a real-world setting, but it also manages to reduce the navigation and search time by approximately 300%. This indicates that GoMap is able to efficiently reduce the time spent on searching and lessen the frustration and anxiety of being lost in an unfamiliar building.

Table 2. Comparisons of the step counting efficiency (time) between participants with GoMap and without GoMap in locating an undisclosed staged room (*Bilik Mawar*)

Participants	With/Without GoMap	Time taken (mins)	Mean
1	With	1 min 45 secs	1 min 51 secs
2	With	1 min 57 secs	
3	Without	10 mins 36 secs	8 mins 42 sec
4	Without	6 mins 48 secs	

6. CONCLUSION

GoMap is an indoor map application developed to help users navigate through the building when trying to locate a specific venue such as a room, a hall, and the washroom. It combines three components–the step counting technique, the augmented reality function, and the accelerometer sensors embedded in most mobile devices. The step counting technique is used to estimate the distances walked from the starting point to the intended location. The augmented reality function uses the actual environment in the building as markers to determine the user's current location as he walks and updates his whereabouts into the system, so that arrows showing the immediate direction to be taken can be displayed on the screen of the mobile device. The third component, the accelerometer detects if the user has taken the correct turn as suggested when there are several path options and updates the moves into the system.

From the two studies, it can be seen that GoMap is a useful application that can help the indoor navigation process. Its accuracy is comparable to Google Fit, which is a common pedometer that can track the number of steps and distances taken by users. Its feasibility was also studied and although the sample size were quite small due to the COVID-19 lockdown, the study clearly indicates that the time and effort taken to search for an unfamiliar room is reduced significantly when GoMap is used.

GoMap has several limitations including that its accuracy and performance can be affected by several external elements such as the is accuracy and sensitivity of the motion sensors (device-dependent), the error in understanding the directions and instructions (human-dependent), the differences in the way that the mobile device is held (device handling), and most importantly, the accuracy of the building's layout and direction details being programmed into the app (content-dependent). In this study, the same model of mobile phone was used and the study was conducted at the same site, in order to ensure that everything was kept constant. However, if installed on a different mobile phone model and make, the results between the devices may have larger inconsistencies. The validity and reliability of step count algorithms on the devices must not be assumed but must be tested and calibrated first to consistency throughout. Regardless, GoMap has shown promising potentials in becoming a principal app for indoor navigation.

REFERENCES

[1] A. L. A. Ramos, K. L. C. Matienzo, J. M. D. Casunuran, C. M. Nervida, J. M. S. Rosal, and A. V. Bederico, "E-Vision: A campus locator map mobile application using A* algorithm," *International Journal of Computer Science and Software Engineering,* vol. 7, no. 1, pp. 6-11, 2018.

[2] A. Abd-Elrahman, M. Duryea, M. Dix, and J. Perry, "Online project mapping with researcher community input," *Journal of Extension*, vol. 48, no. 3, pp. v48-3a3, 2010.

[3] D. Foster, C. Linehan, B. Kirman, S. Lawson, and G. James, "Motivating physical activity at work: Using persuasive social media for competitive step counting," *Proceedings of the 14th International Academic MindTrek Conference*: Envisioning Future Media Environments, New York, NY, USA, 2010, pp. 111–116, doi: 10.1145/1930488.1930510.

[4] K. A. De Cocker, I. M. De Bourdeaudhuij, and G. M. Cardon, "The effect of a multi-strategy workplace physical activity intervention promoting pedometer use and step count increase," *Health Educ. Res.,* vol. 25, 2010, pp. 608–619, doi: 10.1093/her/cyp052.

[5] T. M. Suboc *et al.,* "Relative importance of step count, intensity, and duration on physical activitys impact on vascular structure and function in previously sedentary older adults," *J. Am. Heart Assoc.,* vol. 3, pp. 1–13, 2014, doi: 10.1161/JAHA.113.000702.

[6] B. Huang, G. Qi, X. Yang, L. Zhao, and H. Zou, "Exploiting cyclic features of walking for pedestrian dead reckoning with unconstrained smartphones," *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing,* New York, NY, USA, 2016, pp. 374–385, doi: 10.1145/2971648.2971742.

[7] X. Lu, H. Zou, H. Zhou, L. Xie, and G. Huang, "Robust extreme learning machine with its application to indoor positioning," *IEEE Trans. Cybernetics,* vol. 46, 2016, pp. 194–205, doi: 10.1109/TCYB.2015.2399420.

[8] H. El-Alfy, I. Mitsugami, and Y. Yagi, "Gait recognition based on normal distance maps," *IEEE Trans. Cybernetics*, vol. 48, pp. 1526–1539, 2018, doi: 10.1109/TCYB.2017.2705799.

[9] B. Huang, Z. Xu, B. Jia, and G. Mao, "An online radio map update scheme for wifi fingerprint-based localization," *IEEE Internet Things J.,* vol. 6, pp. 6909–6918, 2019, doi: 10.1109/JIOT.2019.2912808.

[10] Y. Yang, B. Huang, and R. Yang, "A wifi assisted pedestrian heading estimation method using smartphones," 2020 *IEEE 44th Annual Computer Software and Applications Conference (COMPSAC),* New York, NY, USA, 2020, pp. 1–9, doi: 10.1109/COMPSAC48688.2020.0-197.

[11] N. A. Sharin, N. M. Norowi, and L. N. Abdullah, "A user requirements study for developing mobile-based augmented reality indoor map locator application," *International Journal of Advanced Research in Engineering and Technology (IJARET),* vol. 11, no. 12, pp. 1361-1373, 2020.

[12] H. Jeon, U. Jo, M. Jo, N. Kim, and Y. Kim, "An Adaptive AP selection scheme based on RSS for enhancing positioning accuracy," *Wireless Personal Communications*, vol. 69, 2013, doi: 10.1007/s11277-012-0649-8.

[13] P. Brida, J. Machaj, and J. Benikovsky, "A modular localization system as a positioning service for road transport," *Sensors*, 2014, doi: 10.3390/s141120274.

[14] J. Wang, D. Ni, and K. Li, "RFID-based vehicle positioning and its applications in connected vehicles," *Sensors*, 2014, doi: 10.3390/s140304225.

[15] D. Khan, S. Ullah, and S. Nabi, "A generic approach toward indoor navigation and pathfinding with robust marker tracking," *Remote Sensing,* vol. 11, no. 24, p. 3052, 2019, doi: 10.3390/rs11243052.

[16] A. Koyun and I. A. Cankaya, "Implementation of a beacon-enabled mobile indoor navigation system using augmented reality,". *Tehnički vjesnik,* vol. 25, no. 4, pp. 979-985, 2018, doi: 10.17559/TV-20160428091101.

[17] B. C. Huang, J. Hsu, E. T. H Chu, and H. M. Wu, "ARBIN: augmented reality based indoor navigation system," *Sensors,* vol. 20, no. 20, p.5890, 2020, doi: 10.3390/s20205890.

[18] P. Herbers and M. König, "Indoor localization for augmented reality devices using BIM, point clouds, and template matching," *Applied Sciences,* vol. 9, no. 20, p.4260, 2019, doi: 10.3390/app9204260.

[19] D. Acharya, M. Ramezani, K. Khoshelham, and S. Winter, "BIM-Tracker: A model-based visual tracking approach for indoor localisation using a 3D building model," *ISPRS Journal of Photogrammetry and Remote Sensing,* vol. 150, pp. 157-171, 2019, doi: 10.1016/j.isprsjprs.2019.02.014.

[20] D. Yao, D. W. Park, S. O. An, and S. K. Kim, "Development of augmented reality indoor navigation system based on enhanced A* Algorithm," *KSII Transactions on Internet & Information Systems,* vol. 13, no. 9, 2019, doi: 10.3837/tiis.2019.09.016.

[21] H. Bao and W. -C. Wong, "An indoor dead-reckoning algorithm with map matching," 2013 9th *International Wireless Communications and Mobile Computing Conference (IWCMC),* 2013, pp. 1534-1539, doi: 10.1109/IWCMC.2013.6583784.

[22] K. Park, H. Shin, and H. Cha, "Smartphone-based pedestrian tracking in indoor corridor environments," *Pers Ubiquit Comput.,* vol. 17, no. 2, pp. 359–370, 2013, doi: 10.1007/s00779-011-0499-5.

[23] Y. Kim, H. Shin, Y. Chon, and H. Cha, "Smartphone-based Wi-Fi tracking system exploiting the RSS peak to overcome the RSS variance problem," *Pervasive and Mobile Computing,* vol. 9, no. 3, pp. 406-420, 2013, doi: 10.1016/j.pmcj.2012.12.003.

[24] Fitbit. [Online]. Available: https://play.google.com/store/apps/details?id=com.fitbit.FitbitMobile (accessed Nov. 2, 2022).

[25] Noom: Weight Loss & Health. [Online]. Available: https://play.google.com/store/apps/details?id=com.wsl.noom, accessed Oct.25, 2022.

[26] Pedometer - Step Counter App. [Online]. Available: https://play.google.com/store/apps/details?id=com.tayu. tau.pedometer, (accessed Oct 6, 2022).

[27] M. Ciman, M. Donini, O. Gaggi, and F. Aiolli, "Stairstep recognition and counting in a serious Game for increasing users' physical activity," *Personal and Ubiquitous Computing,* vol. 20, no. 6, pp. 1015–1033, 2016, doi: 10.1007/s00779-016-0968-y.

[28] H. Furata, K. Takahashi, K. Nakatsu, K. Ishibashi, and M. Aira, "A mobile application system for sightseeing guidance using augmented reality," *Soft Computing and Intelligent Systems (SCIS) and 13th International Symposium on Advanced Intelligent Systems (ISIS) 2012 Joint 6th International Conference*, IEEE, 2012, pp. 1903-1906, doi: 10.1109/SCIS-ISIS.2012.6505308.

[29] Y. H. Yu, "Study on intelligent augmented reality tourist guide application based on android smart phone," *Applied Mechanics and Materials*, vol. 668, pp. 1399-1402, 2014, doi: 10.4028/www.scientific.net/AMM.668-669.1399.

[30] A. Fevgas, N. Fraggogiannis, P. Tsompanopoulou, and P. Bozanis, "The iMuse Virtual Museum: towards a cultural education platform," in *IISA 2014, The 5th International Conference on Information, Intelligence, Systems and Applications, IEEE*, 2014, pp. 171-175, doi: 10.1109/IISA.2014.6878817.

[31] F. M. N. S. Nurul and G. Masitah, "A systematic review on digital technology for enhancing user experience in museums," *User Science and Engineering: Design, UX and Usability*, 2018, pp. 35-46, doi: 10.1007/978-981-13-1628-9_4.

[32] G. A. Lee, A. Dunser, A. Nassani, and M. Billinghurst, "AntarcticAR: An outdoor AR experience of a virtual tour to Antarctica," *IEEE International Symposium on Mixed and Augmented Reality-Arts, Media, and Humanities (ISMAR-AMH)*, IEEE, 2013, pp. 29–38, doi: 10.1109/ISMAR-AMH.2013.6671264.

[33] P. J. Lin, C. C. Kao, K. H. Lam, and I. C. Tsai, "Design and implementation of a tourism system using mobile augmented reality and gis technologies," in *Proc. of the 2nd International Conference on Intelligent Technologies and Engineering Systems (ICITES2013)*, Springer, Berlin, Heidelberg, 2014, pp. 1093–1099, doi: 10.1007/978-3-319-04573-3_133.

[34] H. Choi, G. C. Han, and I. J. Kim, "Smart booklet: Tour guide system with mobile augmented reality," IEEE *International Conference on Consumer Electronics (ICCE).* IEEE, 2014, pp. 353–354, doi: 10.1109/ICCE.2014.6776038.

[35] F. D. Giraldo, E. Arango, C. D. Cruz, and C. C. Bernal, "Application of augmented reality and usability approaches for the implementation of an interactive tour applied at University of Quindío," in *2016 IEEE 11th Columbian Computing Conference (CCC)*, 2016, pp. 1-8, doi: 10.1109/ColumbianCC.2016.7750798.

[36] H. Fabricio, G. Renan, F. Vinicius, and T. Liane, "Augmented reality impact in the development of formal thinking," in 4th *Annual International Conference of the Immersive Learning Research Network (iLRN2018)*, 2018, pp. 23–34.

[37] Y. Ang, P. S. Sulaiman, R. W. O. Rahmat, and N. M. Norowi, "Swing-in-place (SIP): a less fatigue walking-in-place method with side-viewing functionality for mobile virtual reality," *IEEE Access*, vol. 7, pp. 183985-183995, 2019, doi: 10.1109/ACCESS.2019.2960409.

BIOGRAPHIES OF AUTHORS

Nursyahirah Atikah Sharin is a postgraduate student studying for her Master of Science in Human-Computer Interaction at the Faculty of Computer Science and Information Technology, Universiti Putra Malaysia, Malaysia. She received her Bachelor of Computer Science degree (majoring in Multimedia) at the Universiti Putra Malaysia (UPM), Malaysia in 2017. She is an active member of the Human-Computer Interaction Research Group in UPM, and is also a student member of ACM SIGCHI Kuala Lumpur Chapter (myHCI-UX). Her research interests include mobile interaction, augmented reality, and interaction technologies. She can be contacted at email: nursyahirahatikah.1994@gmail.com.

Noris Mohd Norowi is a Senior Lecturer at the Faculty of Computer Science and Information Technology (FCSIT), Universiti Putra Malaysia (UPM). She is a research member of the Human-Computer Interaction Lab at FCSIT, UPM. She is an active member of the ACM SIGCHI Kuala Lumpur Chapter (myHCI-UX), where she holds the position as the Treasurer for Malaysia. Her research interests include music interaction, immersive technologies, mobile interaction, artificial intelligence in music, sound cognition, and sound synthesis. She can be contacted at email: noris@upm.edu.my.

Lili Nurliyana Abdullah is currently an Associate Professor and Technologist at University Putra Malaysia, Malaysia since 1996. Her research interests include image processing, human-computer interaction and multimedia information security. She is Board of Editors, Editors and reviewer of many journals and proceedings. She has been actively involved herself with research, development and teaching. She can be contacted at email: liyana@upm.edu.my.

Seng-Beng Ng received his B.Sc., M.Sc. and PhD in Computer Science from Universiti Putra Malaysia (UPM), in 2004, 2007 and 2015 respectively. He is currently a senior lecturer in the Faculty of Computer Science and Information Technology, UPM and a member of the Computer Graphics, Vision and Visualisation (CGV2) research group. His research interest is point cloud processing, image-based modelling, and geometrical reverse engineering. He can be contacted at email: ngsengbeng@upm.edu.my.