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Indoor Navigation Systems Using Annotated Maps in Mobile Augmented Reality

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A Mobile Augmented Reality indoor navigation framework composed of several modules to reduce human cognitive workload and save time by blending the digital and physical worlds seamlessly through aligning the appropriate 3D path with features in the real world through ground detection. The framework helps in better understanding the surrounding especially unfamiliar buildings such as offices, shopping malls and libraries etc. It determines the users starting location via scanning the reference image which is placed at the entrance. The system was tested at the Centre for Academic Information Services (CAIS), Universiti Malaysia Sarawak (UNIMAS). The results proved that the system provides a good platform to show the location information without requiring hardware installation and a strong wireless connection.

Key words: *Mobile augmented reality, indoor navigation, annotated maps, global positioning system (GPS), WiFi, sensors, mobile computing.*

Introduction

Indoor navigation is the idea of navigating the user in an indoor environment. Conventionally, people use a paper map or facility directory to see the location of an object and figure out the route to their desired destination. Although GPS-based mapping is introduced and well known for being a precise-positioning tool, it is only applicable for outdoor environments not for indoor because the signals from the satellite to determine a location are attenuated and dispersed by objects such as roof and wall.

The rapid evolution of technology in recent years offered a variety of techniques to facilitate indoor navigation such as Wi-Fi, Bluetooth Beacons and annotated maps. WiFi-based positioning technology is a good alternative solution as WiFi are commonly installed in buildings and it can act as access points. Its data can be used to calculate the current position by using the WiFi positioning system installed in the mobile device (Lashkari, Parhizkar, & Ngan, 2010). However, situation such as building with weak or no WiFi connection might not able to work for this solution. Moreover, WiFi-based systems also encounter signal attenuation due to the propagation effect like reflection or diffraction to the obstacles. Next, alternative technology using Bluetooth in Beacons to transmit the unique signals to the mobile device to further interpret and localise the device (Huh & Seo, 2017). It is a good indoor positioning technology, but it has some weakness like being time-consuming and costly, as many Beacons need to be installed around the building due to a small range of coverage.

As a result, an indoor navigation without the requirement of wireless technology and hardware installation should be implemented to overcome the problem. The proposed framework provides an interactive indoor navigation system through annotated map technique that aims to route the user without the need of internet technology. In addition, it uses an interactive Augmented Reality to support the navigation process, reducing cognitive burdens and engage the user in a more interesting way.

Literature Review

Indoor navigation system

Indoor navigation systems are a system that provides an optimal path between starting point and desired destination in an indoor environment. There are two main elements in indoor navigation systems which are an anchor with its unique location information and a positioning device that is able to process the anchor information in order to determine its own location (Yang & Shao, 2015). Although many potential indoor navigation services have been provided on the market, the ultimate solution is still an arguable issue in terms of accuracy, real time and cost effectiveness.

Typical positioning techniques

Global Positioning System: GPS is the best, well-known outdoor positioning system. It determines the longitude, latitude and altitude of a person's position on earth through satellite (Olevall & Fuchs, 2017). However, the bad accuracy of detecting an indoor position is a well-known issue because the radio signal from satellites is blocked by the construction material like roof and wall (Jekabsons, Kairish, & Zuravlyov, 2011).

WiFi-Based System: WiFi positioning is determined through the WiFi access point (APs) that broadcast a signal that allow the mobile device to calculate the device's current location (Zandbergen, 2009). Hu (2013) discussed the use of Wi-Fi based indoor positioning system in smartphones and pointed out that wireless network is a viable solution for indoor positioning as there is a low cost required and no specialised hardware is needed to set up.

However, it has some disadvantages such as limited coverage and the WiFi signals suffer time-correlated fading effects due to interference from other devices and moving objects (Zandbergen, 2009).

Bluetooth-Based System: Bluetooth beacons have been agreed as the most accurate positioning system among the others. It acts as location awareness by installing the hardware beacons around the building where each consists of unique location data. After that, the beacons message is broadcast as a signal to communicate with the mobile device through Bluetooth Low Energy technology (Pokale et al., 2017). It has been claimed that it only consumes less battery power to broadcast the advertising signals but in fact the accuracy and performance of beacons broadcast is directly proportional to the battery power consumption. Furthermore, according to Olevall & Fuchs (2017), the deployment cost is expensive as the requirement of installing large amount of tracking devices especially for large indoor areas and the support cost of upkeep like replacing the malfunctioning beacons.

Annotated maps: The annotated map is a digital map that combines the traditional paper map with annotations which carry coordinate data and other location information. It serves as a quick overview of the current surrounding to provide spatial patterns and relations (Kraak, 2004). When the user is looking at the map through a mobile device, it defines a cartographic interaction where the map provides geovisualisation to support visually enabled human reasoning (Roth, 2013). However, it is unable to track real-time user's location as it does not integrate with internet technology.

Augmented reality

Augmented reality is a technology that overlays computer graphics that have registered in the 3D space on top of the real world, where the real world is the primary place of action (Silva, Oliveira, & Giraldi, 2003). Besides, both interact with real-time updates where the movement of the user has direct effect ib the virtual element when present on the computing device's screen. It differs from virtual reality as it does not create a whole new artificial world, but it adds some virtual model to the existing physical environment (Chavan, 2014). There are a few types of Augmented Realities as listed below:

- **Marker-based AR:** Marker-based AR is a type of AR that detect the visual marker like QR and 2D through camera's phone. After that, the virtual object is rendered over the marker after series of calculations and considers the angle and distance between a mobile phone and the marker [12].
- **Marker-less AR:** Marker-less AR or location-based AR involved location tool like GPS to obtain user's geographical position so that it shows relevant virtual

information about the nearby landmark or directions of location in augmented view (Chanphearith, Santoso , & Suyoto, 2016).

- **Projection-based AR:** Projection-based AR projects the light of image to the real object which then human can interact with the help of sensors. The masking technique is used to align the projecting image with the object by tracking the object's silhouette (Lee, Kim, Heo, Kim, & Shin, 2015).
- **Superimposition-based AR:** Superimposition-based AR determines a cluster of markers on a real object in order to estimate the local coordinate based on optimisation method (Argotti, Davis, Outters, & Rolland, 2002). After this is all obtained in the transformation matrices, the process of stereoscopic rendering happens to replace the original image with the augmented one.
- In addition to that, there are many existing development softwares for AR like ARToolKit, ARKit, ARCore and Vuforia. Lastly, the advantage of AR is it provides a more "real" gaming experience through enhancing the perception of the user and their interaction. Furthermore, it also applied in education field where the supplementary interactive information like video and graphics make the learning process more interesting and easier to absorb new knowledge.

Mobile augmented reality on indoor navigation

Rehman and Cao (2016) carried out a comparative analysis for an Augmented Reality-based indoor navigation through handheld devices, wearable devices and a paper map. The real time location of the electronic device is determined through the 3D point cloud that previously determined and stored as trackable with location and navigation information. After that, Metaio SDK is used in the system to navigate the user by overlaying the AR information based on 3D point cloud such as virtual arrow as directional instruction associated with audio and text-based visual information. The study revealed that the digital device assists users better in their navigation compared to a paper map in terms of navigation time and workload. Furthermore, there is no significant difference between the use of a handheld and wearable device in terms of performance and workload except the perceived accuracy of wearable device is slightly better but the limited battery resources set a drawback compared to handheld device. It can be concluded that the handheld device is still considered as a good tool to implement the Augmented Reality-based indoor navigation.

Kasprzak, Komninos and Barrie (2013) investigated the use of feature-based indoor navigation using Augmented Reality. The study started with initial prototype in mobile application for user to key in the starting point and destination. After that, the mobile device's location is determined through identifying the building's internal features like door sign or logo of the store as a target marker. The virtual arrow will display on the top of logo accompany with text directions to direct users to their target location. Based on the result, the use of feature-based for indoor navigation shortens the time of task completion as the number of wrong turns and pause performance are lesser compared to those using paper map. This can be concluded that the use of augmented reality improved the indoor navigation performance as the instant direction is given without the need of locating the target and figure out an optimal path manually.

Annotated map for augmented reality

Reitmayr et al. (2010) innovated the Augmented Reality system by adding the Simultaneous Localisation and Mapping (SLAM) to overcome the limitation of AR at unknown environment. SLAM function is posing an estimation of the camera and 3D model reconstruction while moving through environments. Besides, global registration can be done by using panoramic mapping to track the camera orientation and identified the interest points. After that, the stored annotation from the server will be downloaded when the user moves closer to a location with a referenced panorama and matches the new panorama by NCC template matching. The study revealed the use of SLAM to place the 3D annotation geometry accurately. However, challenges like the accuracy of placing the annotation strongly rely on GPS and visual artifacts set the needs for further improvement of the research in the context of the unknown environment.

On the other hand, Langlotz, et al. (2011) proposed an enhanced approach of registering and tracking the annotation for outdoor augmented reality browsing. The panorama images with extended dynamic range is used and matched with the current view by looking for the anchor points. In addition to that, the annotation is redetected by applying global consistency to reduce its position error. As a result, the test case showed an improved accuracy of re-detection rate while running at interactive frame rates. This research shown the value of annotation still possess a usefulness for outdoor augmented reality browsing in alternative way.

Methodology

A research framework was designed based on rapid application development (RAD) model which is shown in the figure 1 below.

There is a total of three phases in this research framework which are analysis or planning, design, development and implementation.

Analysis or planning

The research was done through observation and interviewing the CAIS user about their problem faced in accessing the point of interest. Besides, investigation of current system, collect the existing related information and review similar system to look for reusable structure. Next, data analysis is carried out to determine user requirements and measure with the feasibility to outline a reasonable system architecture. Besides, scope of content is defined like the floorplan of CAIS building, annotation and 3D models are collected. Moreover, technical analysis was carried out.

Design, development and implementation

The system architecture was designed according to user's requirements. The low fidelity prototype is drawn by using pen and paper which the placement of data, sequence and interaction between interface are identified. After that, cooperative evaluation, an observational method which the interviewers have a conversation with the evaluator to discuss about the paper prototype is carried out. This is an essential process to understand user opinion toward the system for further refine the prototype. The process of improvement of prototype and evaluation has been iterated several times until the best prototype is verified. A high-fidelity prototype was designed according to the finalised low-fidelity prototype. The floorplan is edited and styled to a customised map. After that, an acceptance test has been carried out to examine the operational capacity of the system. Lastly, all the prototypes are implemented into a complete system in mobile application named as CAIS Navi.

Testing

Technical evaluation is conducted several times and the refined process is carried out until the mobile application reached the acceptable performance level. Besides, 15 CAIS users who are new, unfamiliar to the CAIS environment and Android users are selected randomly to try the CAIS Navi. The users' responses were collected using System Usability Scale (SUS) scale. It consists of 10 Likert scale questions scaling from strongly disagree to strongly agree. It is selected as a testing tool due to its robustness and rapidness in providing a reliable result on the usability of the mobile app. The system workflow is shown in the figure 2 below.

Results and Discussion

The system was tested at Level 1, CAIS building in UNIMAS. A total of 15 participants were involved in the testing and the testing was divided into two stages. The first stage was testing the image recognition system for reference image detection and response with a rendering of the destination selection panel. This is important as the user starting location needed to be confirmed in order to generate a correct path. The second stage was to present the appropriate 3D path based on user selection and alignment with the real world accurately. The user selected the destination from destination choices available randomly to test the ability of the system to generate the correct path for navigation. The errors appeared during testing were collected during the navigation.

Technical evaluation

The following elements are measured during the process of technical evaluation to understand the several issues that might affect the effectiveness of an indoor navigation system using annotated maps through interactive augmented reality:

The effectiveness of the system in detecting the reference image: During the evaluation, users were assigned the task to scan the reference image in order to pop out the destination selection panel to choose their desired destination. However, in some cases the process took some time on scanning process because the reference image sometimes turns blurry due to the fixed focus point by ARCore (Google Developers, 2019b). The app demands the camera to be position parallel to the reference image and no obscured (Google Developers, 2019c) to ease the image target recognition.

The effectiveness of system in environment detection: After the destination selection, the system will continue activating the camera view for ground detection. It is important for ARCore to understand the real-world environment by detecting the feature points and planes so that the AR scene is aligned properly with the real world (Google Developers, 2019a). As a result, the device overlays 3D maps and location data of CAIS level 1 like the corresponding navigation path, 3D objects, and text-based visual information onto AR camera feed. After carrying out the evaluation, there were 4 participants who failed to properly align the features between physical and virtual world due to the system failing to detect feature points for surface’s angle detection and wrong position the actual location.

Usability evaluation

The system usability scale (SUS) questionnaire has been distributed to the participants after testing the mobile app for the sake of validating the usability of the system and quality of user experience. Fifteen (15) UNIMAS students were randomly selected for this evaluation, the results are shown in the Figure 3 below.

Figure 3 shows the SUS score for 15 users and an average of it is 80.6. Overall, 80% of the users gave more than 80%, an excellent review of the app which reflects the good usability of the application. Indirectly, it indicates the realisation of the project objective in providing interactive indoor navigation.

Key questions results of the usability scale

Precisely, as Fig. 4, 5, 6 and 7 show that 12 out of 15 users strongly agreed that the app was easy to use based on third question (see Fig.6) due to the straightforward function and instructions given. Besides, more than 75% of users under the first question (see Fig.4), agreed that they would like to use the system frequently as they think the app is interesting because it offers a novel way to navigate in CAIS. Conversely, according to the ninth question, 4 out of 15 users (see Fig.7) felt unconfident to use the mobile app because the image recognition at this early stage fails in detection sometimes but the app does not notify the user regarding the issue and is given some tips to overcome it. Moreover, three users in line with second question (see Fig.5), who are new in are using AR app, found the navigation interface is unnecessarily complex because of the split screen for 2D map and AR scene.

Discussion

The indoor navigation mobile AR that implemented in this research poses a few superiorities. The 3D virtual objects bring a new interactive experience on navigation compared to the paper map. Besides, the mobile app only shows the relevant information based on user selection to relieve the cognitive burden and remember the information in a more remarkable way. Furthermore, the app is dynamic as the screen changes based on the devices position and orientation. Lastly, it dispenses the need for hardware installation and strong wireless technology aids to reduce implementation cost.

Weakness of the system

On the contrary, the interactive indoor navigation mobile app expects to work on ARCore-compatible device only which limit the market as many mobile devices lack of support with high processing power. Moreover, the accuracy of image target recognition by using ARCore yet has room for improvements.

Recommendation for future direction

In this research, the indoor navigation mobile AR app only uses one reference image for one starting location. Thus, in future work, more initial positions can be added on to offer more location choices. Besides, the current app only labels the facility's name along the pathway can be further advanced with the addition of detail remarks about the facility. Furthermore, the smoothing algorithm can be applied to enhance the accuracy of the device's position.

Lastly, system status should be conveyed to the user all the time especially during the image recognition process. The system should display the status of failing to detect the referenced image with suggestion after a while so that user will not get lost in control of the system.

Conclusion

This research verified that mobile AR app using the annotated map is an effective solution for indoor navigation without requesting hardware installation and a strong wireless connection. The core of this mobile app is mainly divided into positioning and navigation.

On the other hand, the technical and non-technical evaluation proved the accuracy and usability of the system and good quality of user experience.

Figure 1. Research framework

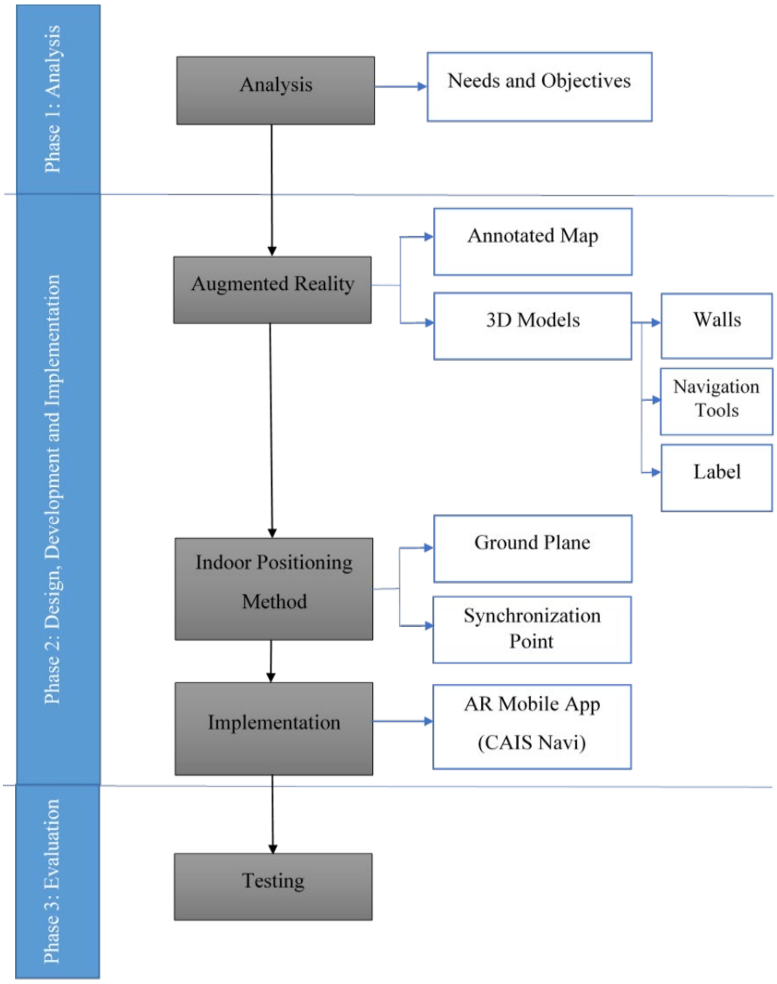


Figure 2. System flow diagram

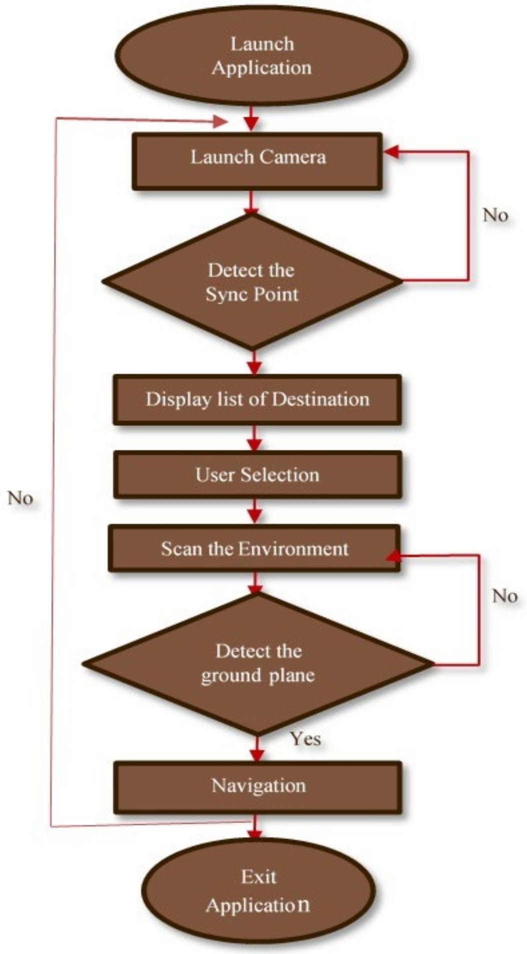


Figure 3. System Usability Result

Figure 4. First question

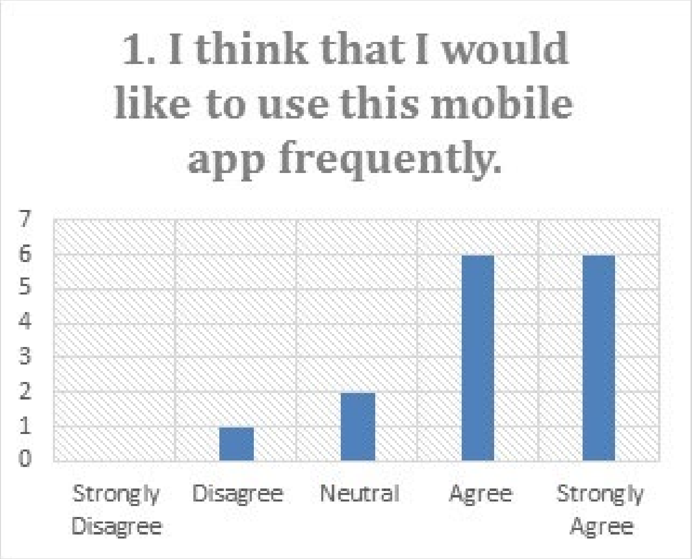


Figure 5. Second question

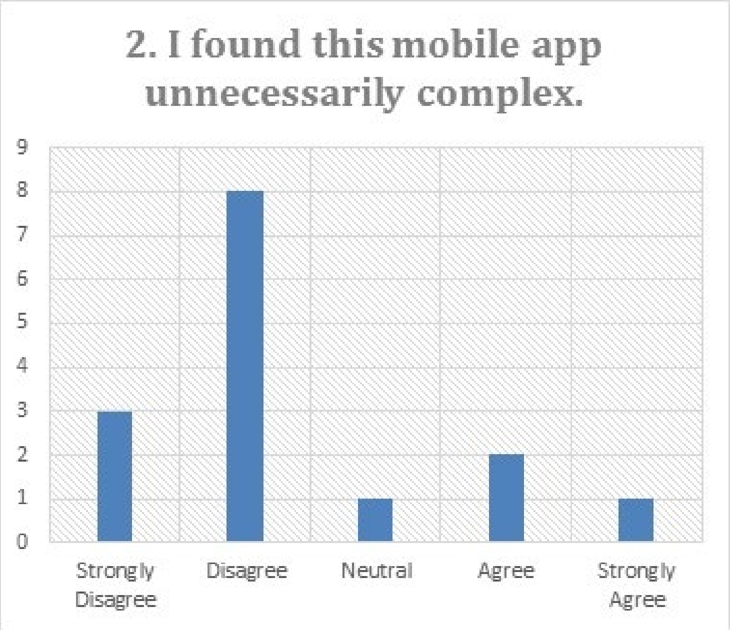


Figure 6. Third question

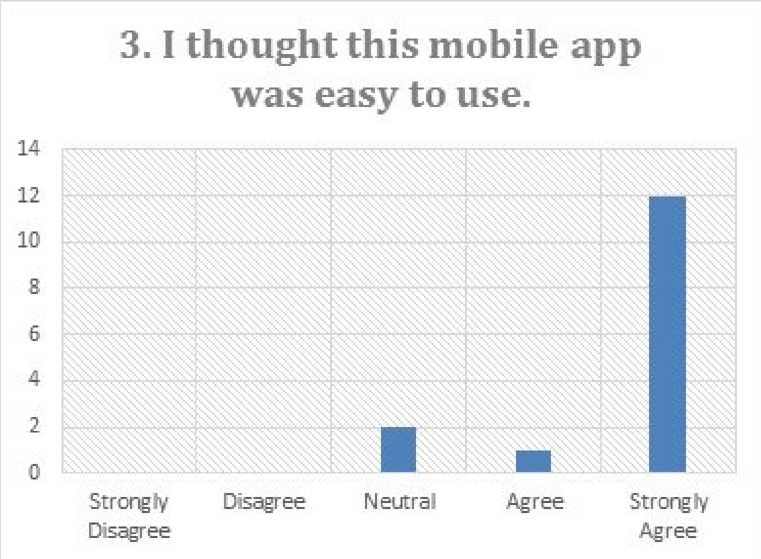
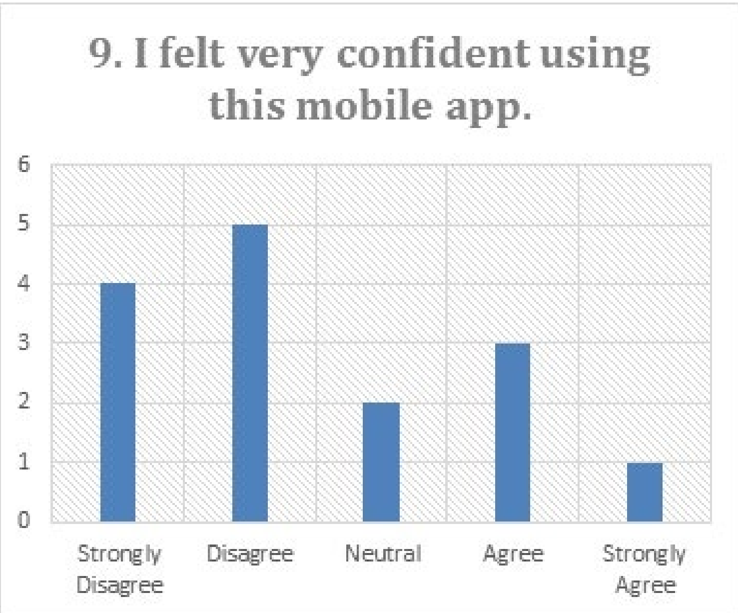


Figure 7. Ninth question



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