A Recommendation for Designing Mobile Pedestrian Navigation System in University Campuses

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ABSTRACT

University campuses have thousands of new students, staff and visitors every year. For those who are unfamiliar with the campus environment, an effective pedestrian navigation system is essential to orientate and guide them around the campus. Compared to traditional navigation systems, such as physical signposts and digital map kiosks, a mobile pedestrian navigation system provides advantages in terms of mobility, sensing capabilities, weather-awareness when the user is on the go. However, how best to design a mobile pedestrian navigation system for university campuses is still vague due to limited research in understanding how pedestrians interact with the system, and what information is required for traveling in a complex environment such as university campus. In this paper, we present a mobile pedestrian navigation system called *QUT Nav*. A field study with eight participants was run in a university campus context, aiming to identify key information required in a mobile pedestrian navigation system for user traveling in university campuses. It also investigated user's interactions and behaviours while they were navigating in the campus environment. Based on the results from the field study, a recommendation for designing mobile pedestrian navigation systems for university campuses is stated.

Author Keywords

Campus Navigation, Pedestrian Navigation, University, Mobile Navigation.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

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INTRODUCTION

Where is the student centre? How do I get to the library? What is the fastest way to get there? These are common questions asked by new university students, staff, or visitors when they are paying a visit to the university campus. In particular, a large number of new students traverse the Queensland University of Technology (QUT) campuses each year (See Table 1).

Year	Number of New Commencing Students
2009	14,289
2010	14,324
2011	14,895
2012	15,894

Table 1. Number of new commencing students at QUT from 2009 to 2012 [15].

For newcomers, navigating in the campus is like going through a maze. Physical signposts and map-based information are currently installed around the campus in most of the universities and colleges to provide guidance. However, they are not sufficient enough for users to feel intuitive [18] and it can be difficult for users to reach their desired destination [12, 16, 9]. Therefore, it is clear that navigating in university campuses can be a challenging task for those who are not familiar with the university environments.

The portability of mobile devices allows people to use their smartphones as personal navigation assistants without searching for signposts constantly around the campus. With mobile sensors and wireless technologies, these devices have the potential to solve the problems faced by the students, staff and visitors when navigating in university campuses. Much research has been conducted to demonstrate how mobile sensors on these mobile devices (e.g., Global Positioning System (GPS), digital compass, microphone, Wi-Fi) could be used to improve identifying a user's location in an indoor and outdoor environment, as well as understanding the situation around them (e.g., weather condition, or meeting availability). There have been many navigation systems developed for university campuses before [8, 25, 2, 19]. Yet, there are only a few research studies [18, 12, 13] that focus on using mobile platforms to help people navigate within a university campus. It is also unclear how we can design a mobile pedestrian navigation systems for those who are unfamiliar with the university campus. There are a few design guidelines for developing pedestrian navigation systems [17, 11]. However, how to best design a mobile-based pedestrian navigation system for the university campus is still vague due to limited research in understanding how pedestrians interact with the system, and what information is required for traveling in complex environment such as university campuses.

In this paper, we reviewed existing navigation systems on mobile devices and in universities, identify the information needed by pedestrians navigating through the university campuses, investigate pedestrian interactions and behaviours when using a mobile application for their campus navigation, and lastly identify the implications for the design of a mobile pedestrian navigation system for the university campuses.

REVIEW OF USER REQUIREMENTS

Navigating around in university campuses can be difficult for new students, staff and visitors who are unfamiliar with university environments. Most universities and colleges rely on installing physical signposts and map-based information around the campuses to help students, staff and visitors to navigate [12, 18]. Even though these physical signposts provide building and road information about the campus, they do not necessarily provide the best information to direct people when needed. For example, a student is attending a lecture on campus, but forgets to bring an umbrella on a rainy day. Using these signposts, they are unable to determine what is the most sheltered route to take from the map without getting wet. These physical signposts are fixed at a location, if they are not easily located, they cannot provide assistance when a user is lost in the middle of the campus.

In order to develop an understanding of the needs of a mobile pedestrian navigation system, a focus group was conducted in order to identify user-requirements when university students and staff are navigating the campus. The focus group comprised of a questionnaire, a group discussion, and a series of scenarios to walk through as a new visitor on campus. This study provided a useful insight into the key problems university students and staff have when they are travel on campus.

This focus group was held with the seven participants who are currently students and staff in QUT, aged from 27 to 38 years old. All the participants had been studying or working for the university for at least one year. They reported they visit the campus regularly (at least 3 times per week, average 4.3 times, SD=0.8), and they felt they were familiar (average of 68.3%) with the university environment. In addition, they were all frequent users of smartphones, with at least two years of experience using one.

An opening discussion was conducted to discuss the general issues that the participants had towards campus navigation. Participants expressed they had difficulty locating specific buildings and finding the services on campus. Due to the fact that the university has limited physical signposts around the campus, and the university mobile application does not provide information on pedestrian routes, bridges or walkways on the campus. They also mentioned the importance of opening hours, and building entrance information when navigating on campus.

Subsequently, participants were asked to react to a series of scenarios as a new visitor who had not been to QUT before and needed to be at a particular place on campus. It involved participants explaining their techniques of completing each task and proposing alternative solutions. The key information required for a mobile pedestrian navigation system was identified, this included:

- The location of the destination and the surrounding university buildings.
- The pedestrian routes available for both indoors and outdoors.
- Travel estimation information on the distance and time.
- Walking routes that take weather conditions into consideration.

Based on the results gathered from the focus group, we have identified some important information required by the pedestrians who are traveling around the university campuses (listed above) and discovered the physical signposts were still the main method used for navigating around the campus for all the participants. Participants confirmed that the current methods of campus navigation do not provide information on indoor and outdoor pedestrian routes, travel estimation and weather-aware walking options. Evidently, this provided us with opportunity for further research to address this issue of how to design a mobile pedestrian navigation system for university environments.

REVIEW OF EXISTING NAVIGATION SYSTEMS

Existing Navigation Systems on Mobile Devices

There are several existing mobile map applications that support walking navigation. Based on the featured navigation applications on the Australian iTunes App Store [1], the popular ones include *Google Maps*, *Apple Maps*, and *Whereis Maps* by Telstra Corporation. These applications are primarily designed to deliver turn-by-turn navigation for driving vehicles in cities with roads and bridges. QUT is a university located next to the Brisbane central business district, and its campus is in a non-linear and an undulating environment with most roads

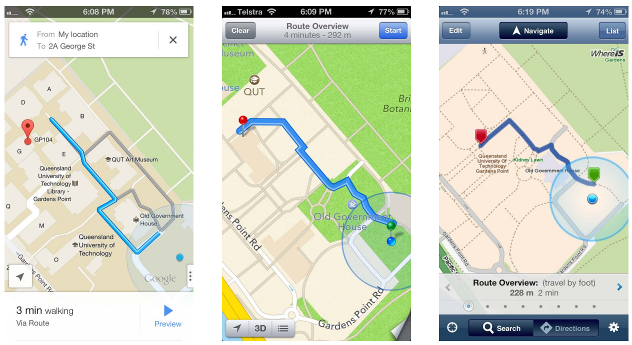

Figure 1. Screenshots of walking routes provided by Google Maps (left), Apple Maps (middle), and Whereis Map (right) mobile application.

and walkways only accessible by pedestrians, and with very few roads being accessible by vehicles.

In Figure 1, we demonstrate a route from a user's current location to one of the university buildings in Google Maps, Apple Maps and Whereis mobile applications on Apple's iOS platform. The walking routes provided by these map navigation applications are quite similar, owing to the fact that these routes are based on the road data in their Geographic Information System (GIS). The routes presented by these applications are not the most appropriate for pedestrians to take, because they lack information on indoor routes. By providing indoor routes to pedestrians, users can cut through buildings and save time on their campus navigation.

Existing Navigation Systems in Universities

Most Australian universities used physical map-information signposts or digital map kiosks as their navigation systems to help people to navigate within the campus. Most of these universities provide their campus maps on their university website. Some of the universities also offer a mobile version of their campus map for users to download onto their smartphones [20, 21]. However, these mobile applications do not provide appropriate pedestrian paths or walkways to provide assistance on campus navigation based on users' needs.

Here2There Software - Kiosk-Based

Temple University in Pennsylvania, United States has adopted *Here2There* (H2T) software [6] to provide an interactive web-based interface to facilitate indoor and outdoor direction to and from any point of the interest on campus. It provides location information on elevators, stairs, wheelchair accessible entrances, and pedestrian exits on a map. Moreover, it provides visual floor plans of each building, with navigation routes clearly displayed. This system can be deployed on a Kiosk, LCD or through a web interface, installed on the walls around the campus, similar to the physical signposts. It can also be deployed in hospitals, shopping malls and airports.

Recently, this technology has been adopted by the Queensland University of Technology [5] in their new Science and Engineering Centre building. However, many problems still exist. For instance, as the direction information is fixed in a database, the system can only show you one way of getting to a destination, without considering how a user would like to get there based on his/her need or situation. Also, it currently has no support for mobile devices, as a result, it cannot utilise mobile sensors to help retrieve a user's location and provide turn-by-turn navigation. Moreover, the availability of these kiosks machines is extremely limited, as the machines are expensive (including buying a computer and a touch screen) and difficult to install and maintain (requiring a weatherproof place) and the system can only be used by one person at a time.

Web-based Campus Navigation Systems

There are a few existing web-based university navigation systems designed for Internet browsers. The University College of London has developed a web-based campus navigation system called *UCL Campus Finder* [23] using the Google maps API. The system has a *find a route* feature to provide pedestrian routes from one university building to another. Moreover, a user has the option to select routes that are accessible via wheelchair. It also provides an estimation of travel time and textual turn-by-turn directions. [8] presented a web-based campus guidance system using OpenStreetMap that focuses on pedestrian navigation, generating the shortest pedestrian routes using both outdoor pavements and indoor corridors between various buildings. It provides support for conference delegates attending the International Conference at the National University of Ireland Maynooth (NUIM) campus. They also used geo-tagged images for visual assistance in pedestrian navigation. These images are used at certain points in the route, such as intersections, when users need the most feedback.

The downside of these systems are that they are only available via a web browser, they do not utilise the sensing capabilities on the smartphones, such as using GPS to retrieve a user's location, and using the camera to provide visual feedback. If these systems adopt the sensing capabilities of these mobile devices, they have the potential to greatly assist users when they are actually navigating on campus.

Indoor Positioning Campus Navigation System

Wireless Trondheim and Norwegian University of Science and Technology (NTNU) developed a mobile application called *CampusGuiden* [24]. It is a world first application developed for indoor positioning for university campuses. CampusGuiden is able to pinpoint a user's location inside a building, and map it to the floor and room the user is currently in. They used NTNU's Wi-Fi network to determine a user's indoor location, and were able to provide an accuracy of up to 10 meters. The system also used GPS positioning when a user is in an outdoor environment. Both indoor and outdoor routes were taken into account to guide users from one location to another. CampusGuiden is a web-based system; it can be run on any Internet browsers found on most of the modern smartphones and desktops computers. However, it lacks mobile sensor support, such as using a digital compass for orientation.

Audio-based Campus Navigation System

CaNPAs [2] is a campus navigation and parking assistant system designed for National Tsing-Hua University (NTHU) in Taiwan. It consists of two components, a *Campus Navigator* (CaN) and a *Parking Assistant System*. The CaN uses voice instructions to guide users around the campus. The audio instructions are provided at every intersection along the route, and it can also recognise and provide audio feedback when users are not going in the right direction. The CaNPAs is deployed on a small external portable device, which is a disadvantage, because users are required to carry an extra device, rather than using their own mobile phones.

The Gap

The results from our focus group show that current navigation systems are still lack of providing necessary information for pedestrians who are traveling in a university environment. Popular mobile navigation systems (e.g. Google Maps), and existing navigation systems in universities do not provide key information required by the pedestrians, and appropriate interactions with the mobile pedestrian navigation system in complex environments such as university campuses.

The main purpose of this study is to investigate pedestrians' interactions and behaviours, and confirm the key information required for pedestrians who are traveling in a university environment. In addition, these findings could potentially help on how an ideal mobile pedestrian navigation system should be designed. To address these research problems, the following questions were asked:

- What information is needed by the pedestrian navigating in university environments?
- How can we design a pedestrian navigation system to adopt pedestrians' interactions and behaviours and provide better assistance while they are traveling in a university environment?

SYSTEM DESIGN

QUT Nav is an iOS mobile application developed and designed for this study. The application is compatible with iPhones and iPod Touches running iOS 6. It serves as a digital campus map, and the map is built on Apple's Geographic Information System (GIS): Apple Maps. The application provides walking directions to any buildings located at the QUT Gardens Point campus. The map also provides geo-location information of the university buildings, images of each building, and building information such as levels, opening hours and the number of floors.

To address the research gaps described earlier, the system was designed with three distinct components: a Map component, a Route component and a Direction engine. (See Figure 2).

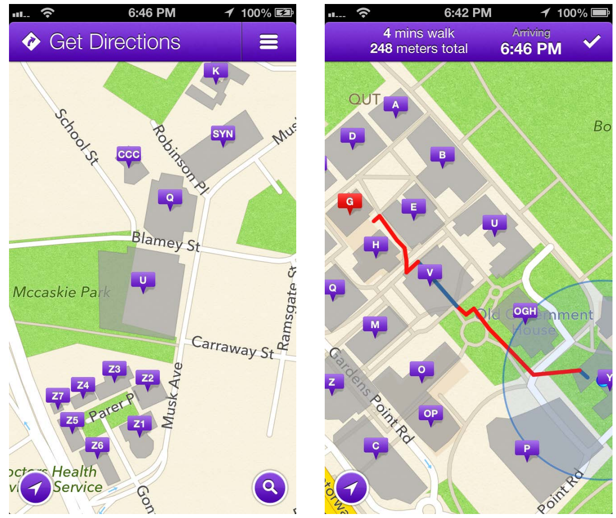

Figure 2. Graphics interface of the Map component (left) and Direction engine (right).

The ***Map component*** contains a digital map that displays a user's current location and the buildings within the university campus. A user's location is represented as a blue dot, and building layouts are overlaid on the map with a square pin on top to display the name of the building. Users are able to scroll, zoom, center and rotate the map based on the device orientation. When launched, the application automatically displays the nearest campus to the user's location, using GPS.

The ***Route component*** contains information on pedestrian routes across the campus. A route is formed by a number of edges. Each edge is formed by two geo-coordinates and presented as a straight line. All the edges have attributes to describe its condition and characteristic. For example, each edge will have information on the travel distance, and whether it is under-cover or protected with a roof, which can prevent pedestrians from being exposing to sunlight and heavy rain. Route information is gathered from both outdoor pavements and indoor corridors between various buildings.

The ***Direction engine*** is the core feature that connects the Map and Route components together. It is capable of retrieving the location of the departure building and all the possible routes to reach the destination building. The engine used Dijkstra's shortest path algorithm [4] to find the minimum-cost pedestrian route based on starting point and destination. The engine also has the ability to calculate routes from a user's current location on the map, enabling those people who are unable to locate themselves on the campus.

STUDY DESIGN

The study was designed as an empirical field test with eight participants. Participants were asked to perform nine navigation tasks provided by the QUT Nav mobile application. The aim of the study was to identify the required information for designing a mobile pedestrian navigation system in a university campus setting, as well as investigate pedestrians' interactions and behaviours with the system while they are traveling in a university. These two goals allowed us to provide initial recommendations for designing a mobile pedestrian navigation systems for university campuses.

Settings of the Field Study

The study area was located at the QUT Gardens Point campus in Brisbane, Australia. A starting point and another two locations were pre-defined for the participant to navigate to. The whole route was approximately 633 meters long, and it took on average around 11 minutes to complete on foot. The route was split into three sub-routes (sub-route #1: 242 m, sub-route #2: 231 m, sub-route #3: 160 m). These sub-routes were arranged in a way that there was never a direct path or line of sign between the start and the destination (See Figure 3).

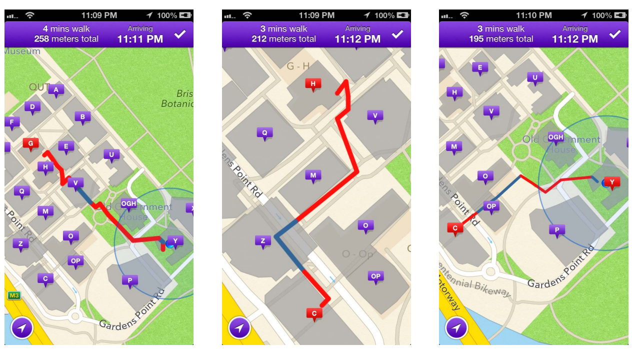

Figure 3. Screenshots of the three campus walkabout tasks. Sub-route #1 (left), #2 (middle), and #3 (right).

Participants

A total of eight participants were recruited to trial the QUT Nav mobile application at the Gardens Point campus. The participants were carefully selected based on their experience with smartphones in general, and especially their experience with the devices in the context of mobile navigation. None of them were familiar with the navigation tasks and pre-defined location.

Experimental Design

This study was designed as an empirical field test, verified by observation and user experiences. Each participant was accompanied by one researcher throughout the study. In order to avoid any influence on the participants, the researcher kept a fair distance (5 meters) from the participants, allowing them to feel freer and behave more naturally while completing the given tasks. This study also includes the rationale for the selection of the current research methodology and procedures. It consists of a survey, a questionnaire, a think-aloud protocol, campus walkabouts, and interviews.

Measures

QUT Nav was designed to collect device logs such as GPS accuracy and location movement of the users. It also utilised the front-face camera on the mobile device to perform video recording to capture each participants' facial emotion, talk, and gestures performed on the device screen. This allowed us in-depth analysis of participant's behaviours, movements and feelings. The video recording feature was implemented using *CaptureRecord* framework [3] for iOS.

In addition, questionnaires were used at the beginning and the end of the field study to collect the participant's demographic information and their experience using the system. It is an effective method to collect in-depth qualitative data, compared to other common study instruments such as interviews and observations [7]. During the navigation tasks, the think-aloud protocol was applied for collecting data on a user's thoughts. This method has also been used in previous studies [7, 10, 14]. This technique was used in conjunction with video recording. It is aimed to collect first-hand information of participants' thoughts and opinions during their navigational tasks. Lastly, one researcher followed all eight participants throughout the campus walkabouts, and observed their reactions to the information received from the smartphone using an audio recorder.

Procedure

All eight participants were met individually in a meeting room on the university campus. At the beginning, each participant was given an overview of this field study. Then, the participant was asked to fill out a survey electronically via a survey system providing demographic information, their experience with mobile devices, and mobile navigation systems usage.

Next, the participant was given an iPhone 5 (same device was given to all the participants), and asked to use the QUT Nav to complete the given navigation tasks. The navigation tasks included physically navigating around the university campus from a pre-defined starting point to the given locations. Each of the participants was advised to navigate to the destination directly avoiding unnecessary stops. They were also asked to verbalise their thoughts, feelings, what they see, or what they were doing while performing the navigational tasks. No other assistance was given during navigation.

After completing each task, the participants were notified of their next task. When all the tasks were completed, participants were asked to complete a questionnaire about their navigation experiences and usability of the system. The questionnaire consisted of 16 five-point Likert scaled questions and three open-ended questions. These questions were broken into five sections: General Usage of the Mobile Application, Usefulness of Travel Prediction, Usefulness of Pedestrian Route, Difficulty of the Navigation Tasks, and Navigation Efficiency.

Once the questionnaire was completed, a semi-structured interview was conducted to facilitate the questions not included in the questionnaire. The open-ended questions included a discussion of any barriers that occurred during the campus walkabouts, as well as different behaviours noticed by the researcher. This interview ran on an average of ten minutes per participant, and recorded by an audio recorder. The audio recording was transcribed later on for analysis. Finally, participants were rewarded with a drink voucher as a token of appreciation.

Navigation Tasks

A total of nine tasks were given to each participant to complete using the QUT Nav mobile application. These tasks were designed to identify the information needed by the pedestrians, and discover the usefulness of pedestrian route choices and travel prediction information provided by the mobile application. All the participants were required to complete the tasks in the same order, this is to ensure results gathered, and their experiences, were consistent.

There were six navigation tasks involving locating a specific building on the campus (e.g. locating the library building), discovering how many levels a particular building has, and figuring out the distance between a specific building and the user's location. The other three navigation tasks were campus walkabouts (See Figure 3), each task involved participants to physically navigate from one specific university building to another within the campus. Each task was considered complete when user reached their destination.

RESULTS AND ANALYSIS

In this section, the results and data collected from the questionnaires, interview, observations, and video recordings from the field study are presented. All the participants completed the navigation tasks and reached each destination successfully. As discussed in the previous section, the information required in a mobile pedestrian navigation system for university campuses, and a user's interactions and behaviours using QUT Nav, were assessed.

The quantitative data collected from the questionnaire were analysed statistically. The data collected from the interview and video recordings were reviewed and translated into scripts for qualitative analysis. When transcribing the video recordings, we annotated the participants' speech, emotions, and behaviours along with the tasks that they were doing. Then we categorised these notes into themes for different tasks. From the key themes and their related materials (e.g. video, audio), we identified the problems, patterns, and contrasts.

Overview

A total of eight participants took part in the study. The youngest person was 23 years and the oldest 39 years ($mean = 28$; $SD = 5.45$). All the participants reported there were a frequent user of mobile navigation technology (frequent usage was specified as being a minimum of once per month), and indicated they had used mobile navigation systems (e.g., Google Maps and Apple Maps) on their mobile devices previously. This helped us to eliminate the potential novelty factor of using a mobile navigation system. Furthermore, none of the participants had used any navigation systems to navigate university campuses before, and none of them expressed they were familiar with the campus walkabout tasks.

Information Required in Pedestrian Navigation System for University Campuses

The information required for designing mobile pedestrian navigation systems was analysed.

Building Entrances

In a non-linear environment with a crowded building complex, like QUT's Gardens Point campus, different buildings have a different number of entrances based on the structure of the building, and the distance to each building entrance from one location may be shorter or longer. When participants were asked about whether building entrances and entrance types matter to them when using QUT Nav 6 out of 8 participants (75%) pointed out the pedestrian route to different building entrances (such as lifts, and stairs) mattered to them when they are navigating on campus.

> *"If there is a lift, then what is the point of taking stairs. That's in my personal opinion. However, some people would prefer stairs."*

> *"I change my mind depending on how tired, how lazy, how time-limited I am when I'm traveling."*

Building Icon Representation

There are more than 25 buildings on the campus, the only way to differentiate between the buildings visually is by their names, or by the alphabetical letters represented the building. Participants were able to locate the building easily by scanning these building identities. However, when they were asked to find the library building on the map, most of them struggled to find it quickly. Various techniques were used by the participants to locate the building, such as searching, panning and zooming on the map, and also looking to find clues from buildings images. However, none of them were able to find the building quickly and accurately. One participant expressed in the interview that if the buildings (e.g., library or IT helpdesk) that were important to them were highlighted on the map or represented with different image icons, it would be much easier for them to locate.

Coloured Routes

QUT Nav was designed to provide the shortest route to a destination, some routes were provided with a sheltered and an unsheltered route. All the participants were able to differentiate the sheltered and unsheltered route when they were navigating around the campus. In the interview, one of the participants mentioned that he did not notice the differences in coloured routes prior to the navigation, he only realised once he had walked past a sheltered route.

Travel Prediction Information
Most navigation systems like TomTom [22] provide travel estimation and arrival time. In QUT Nav, estimated distance, estimated time, and arrival time were provided for participants navigating around the campus. We used a t-test to analyse the data gathered from the questionnaire (See Figure 4), there were no clear differences on the usefulness of travel estimation information (p >0.05). It does not show significant evidence as to which piece of travel prediction information was more useful for the participants during travel. This result might be affected by the participants who were in the context of completing a given tasks. Thus, the results might be different in a real world scenario.

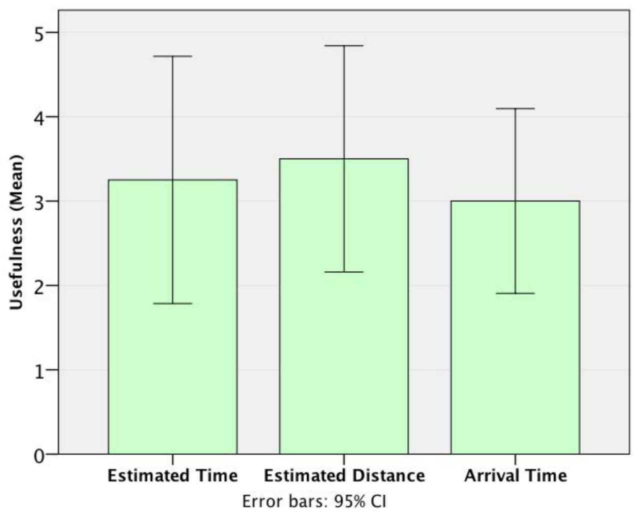

Figure 4. A bar chart shows the usefulness scores (score >3) for different travel estimation information.

Accurate indoor location
QUT Nav utilised the built-in GPS and Wi-Fi sensors on the iPhone 5 to pinpoint a user's location on the map. Based on the analysis of the video recordings, all participants often pointed out that their location was represented inaccurately and inconsistently, especially when they were going through a building. Several participants indicated that their location displayed on the map was not following their actual location, and presented inaccurately when they were going through the buildings.

Route Choices
There are many ways to get from one place to another, and we all want to get there in the shortest time possible. However, providing the shortest route may not always be appropriate for pedestrians. Google Maps on the iPhone provides multiple walking directions based on distance. In this field study, route choices based on distance, weather, lighting conditions, crowdedness, and elevation climb were investigated (See Figure 5).

The shortest route option was provided in the QUT Nav mobile application. All the participants were asked about the usefulness of other types of route choice. Table 2 shows the mean, the standard deviation, and the significant p value of the usefulness score for each type of route. Shortest and sheltered routes showed significant results on the usefulness score (p <0.05), which suggest that a mobile pedestrian navigation system that provides the shortest and sheltered options could be beneficial for pedestrians traveling in a university campus setting.

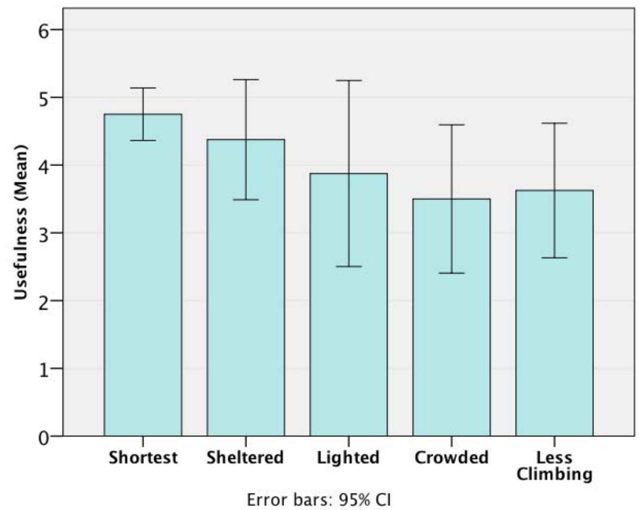

Figure 5. A bar chart shows the usefulness scores (score >3) for different types route choices.

Type of Route	Mean	SD	Sig. (2-tailed)
Shortest	4.75	0.463	0.000
Sheltered	4.38	1.061	0.008
Illuminated	3.88	1.642	0.175
Crowded	3.50	1.309	0.316
Less Climbs	3.63	1.188	0.180

Table 2. Usefulness scores for different types route choices.

User interactions with mobile pedestrian navigation system
To design the most effective pedestrian navigation system, participants' interactions and behaviours were analysed.

Willingness of Using Mobile Application
The QUT Nav mobile application was designed for Apple's iPhone and iPod Touch devices. Most of the participants (7 out of 8) said it was easy to use the mobile application on the iPhone 5, and felt it had helped them to navigate around the campus. Most of them (7 out of 8) also expressed they were very likely to use app again in the future.

Route Overview
During the campus walkabout tasks, all of the participants panned around and zoomed out of the map to

view the entire route that was provided. 7 out of 8 participants indicated in the interview that seeing the whole pedestrian route before they started their navigation gave them a good idea on how they should navigate through the campus. For example, the route required user to walk through a specific building or on a specific walkway.

Map Rotation based on User Orientation

During the campus walkabout tasks participants felt frustrated because they could not locate themselves and identify the direction they were heading on campus. Most of the participants (7 out of 8) tried rotating the mobile device physically to match their location with the surroundings. In fact, QUT Nav was built with standard *Map rotation* functionality that utilised the digital compass on the smartphone to provide map orientation. However, the participants expressed they were not familiar with the standard map rotation functionality on iOS, therefore they did not know the function existed. They also preferred the map to rotate automatically when they were navigating around the campus, rather than having to turn the feature on manually.

Destination Arrival Notification

Current mobile navigation systems such as Google Maps and TomTom [22] provide an audio message to notify users when they have reached their destination. Based on the video recordings and observation during the field study, most of the participants (7 out of 8) stopped looking and interacting with the screen when they had their destination in sight. This finding indicates that users intended to stop any interactions with the system once they were near, or had the visual sight of their destination. Therefore, an additional feature to notify users (such as device vibration or audio reminder) when they reached their destination may not be necessary. However, this feature might be useful for those who are visually impaired.

User Preferences Affects their Walking Choices

QUT Nav provides the shortest pedestrian route to reach the destination. However, 5 out of 8 participants did not follow the given route, because it felt unfamiliar to them. They expressed that they would spend more time following the given route than following the route they are already familiar with. One of them mentioned they took a different route because they were able to see a route that they felt more comfortable walking on it.

In addition, it was midday and the weather was sunny when one of the participants was undertaking a campus walkabout task. While he was navigating to the destination, he decided not to follow the given route that was outdoor and in the open air, and chose to navigate under a sheltered route in a nearby area. He mentioned the weather was hot, and he preferred to navigate under a sheltered route as much as he could, as long as the route was not too far away and did not consume a lot of time. Furthermore, there was a little rain on the campus before one participant undertook one of the campus walkabout tasks. QUT Nav generated the shortest pedestrian route and it indicated the participant to walk across the grassy areas to save time. However, the user purposely avoided walking on the grass. He was asked why he did not walk across the grass in the interview. He responded:

> *"I knew it was raining before and the grass is still wet and I didn't want to get my shoes dirty in the mud."* he said.

DISCUSSION

The main objective of this study was to (1) identify the information needed by pedestrians navigating through the university campuses, (2) investigate pedestrians' interactions and behaviours when using a mobile application for their campus navigation, and (3) identify the implications for the design of a mobile pedestrian navigation system for university campuses. The previous section addressed the required information and the user interactions with the campus pedestrian navigation system through analysing the field study results. Based on these findings, guidelines on how to design for better assisting pedestrians in a university campus are discussed as following.

Information such as building entrances, displaying buildings with icons, and colouring indoor and outdoor routes on the map were identified as key in mobile pedestrian navigation systems. This result is consistent with the recommendations concerning the design of pedestrian navigation systems in a town centre [11], if considering the university buildings are shops. In this field study, participants expressed that the different types and locations of building entrances were important to know when choosing a walking route. This would enable users to select a route that meets their needs, for example: access via the lifts or the stairs. Having coloured routes can help a user identify routes that are sheltered or unsheltered. However, for travel estimation information such as estimated distance, time, and arrival time, there was no clear evidence to show that this was useful or useless towards the system. For route choices, shortest and sheltered route options showed to be significantly more useful than routes that were illuminated, crowded, and had less elevation climb.

For user interactions with pedestrian navigation in university campuses, it was identified that the system must provide assistance for identifying a user's orientation. This has the potential to reduce the number of times a user gets lost during the navigation, as well as reduce feelings of frustration. This feature can be achieved by utilising mobile sensors (such as digital compass and GPS) to rotate the map accordingly and display a user's current location. Some of the participants mentioned they preferred the system to provide them with their orientation automatically. The system should also provide pan and zoom features, as users intend to preview the entire pedestrian route before their navigation. Map rotation and interactions were also considered an important design feature for pedestrian navigation systems [17]. Furthermore, even though QUT Nav provided the shortest walking route to assist participants to navigate from one building to another, some participants did not follow the route provided. It was identified the choice of walking route was based on a user's preference such as their comfort level and their familiarity of the street, as well as the weather condition at the time. Rainy and sunny weather conditions also made users travel more via sheltered paths (users stated they preferred to travel through an air-conditioned building on a hot day).

There was also an issue with location sensing on Apple's iPhone 5. QUT Nav was designed to use the built-in mobile sensors (GPS and Wi-Fi) to identify a user's indoor and outdoor location in a non-linear environment with a crowded building complex. The majority of the participants indicated their location was represented inaccurately and inconsistently. Hence, other techniques such as Bluetooth technology or RFID tags may need to be incorporated into the system in order to improve location sensing on these modern smartphones.

This key information and the user interactions identified should be taken into consideration when designing a pedestrian navigation system for the non-linear environment with crowded buildings like university campuses.

CONCLUSIONS

Navigating in a non-linear and undulating campus environment such as university campuses is difficult for new students, staff and visitors. A mobile pedestrian navigation system that is designed with necessary information and that adopts a user's interactions could be a more useful navigation system than those existing. This paper investigated the research gaps of designing a mobile pedestrian navigation system for university campuses. A focus group to identify the current issues faced by the university students and staff when they are navigating around the campus in QUT was conducted, and a review of existing navigation systems on mobile devices and in universities has been outlined. Key information identified from both the focus group and the navigation system reviews were used to guide the design and implementation of the QUT Nav mobile pedestrian navigation system. A field study to identify key information needed and a user's interactions and behaviours in designing a mobile pedestrian navigation for university campuses was carried out and the results discussed. Findings suggest the QUT Nav was easy to use and helped campus navigation in general. Additionally, by taking the information identified and the user's interactions and behaviours when navigating in university campuses, it is possible to design a more useful pedestrian navigation system for environment such as university campuses.

In conclusion, the results of this study contribute some initial design recommendations for creating mobile pedestrian navigation systems for university campuses, theses include:

- The map should provide rotation based on user's orientation.
- Provide shortest and sheltered route as walking route options.
- Other location sensing techniques may be needed to improve location sensing on modern smartphones (e.g. iPhone 5).
- The map must have zoom and pan features.
- The location of the building entrances and entrance types should also be considered when generating pedestrian route.
- Sheltered and unsheltered pedestrian routes should be represented by different colours.
- The representation of the building icons should be differentiate with their names or alphabetical letters represented.
- The system must allow users to preview the entire pedestrian route before the start of their navigation.
- User preferences has an affect on pedestrian's walking choices.

REFERENCES

1. Apple Inc. Navigation - App Store Downloads on iTunes. Retrieved 20 March, 2013, from `https://itunes.apple.com/au/genre/ios-navigation/id6010?mt=8`.
2. Chou, T. S., Ku, I., Wu, C. H., Hsu, L. C., Lin, Y. S., Chen, Y. T., Huang, T. Y., and King, C. T. CaNPAs: A Campus Navigation and Parking Assistant System. In *Systems, Man and Cybernetics, 2006. SMC '06. IEEE International Conference on*, vol. 1 (2006), 631–638.
3. CocoaControls. CaptureRecord: User and Screen Recording iOS SDK. Retrieved 22 March, 2013, from `http://www.capturerecord.com`.
4. Dijkstra, E. W. A note on two problems in connexion with graphs. *Numerische Mathematik 1*, 1 (1959), 269–271.
5. Global Software Applications. QUT Science and Engineering. Retrieved 15 March, 2013, from `http://here2theresoftware.com/qut/?kiosk=Y6KIOSK`.
6. Global Software Applications. University Digital Wayfinding. Retrieved 15 March, 2013, from `http://www.here2theresoftware.com/Education.html`.
7. Ingwersen, P., and Järvelin, K. *The Turn: Integration of Information Seeking and Retrieval in Context (The Information Retrieval Series)*. Springer-Verlag New York, Inc., 2005.

8. Jacob, R., Zheng, J., Ciepłuch, B., Mooney, P., and Winstanley, A. *Campus Guidance System for International Conferences Based on OpenStreetMap*, vol. 5886 of *Lecture Notes in Computer Science*. Springer Berlin Heidelberg, 2009, ch. 13, 187–198.

9. Jacob, R., Zheng, J., Ciepłuch, B., Mooney, P., and Winstanley, A. C. A Multi-lingual pedestrian navigation and campus guidance system using CloudMade API. B. G. Lees and S. W. Laffan, Eds., University of New South Wales (University of New South Wales, Sydney, Australia, 2009).

10. Jaspers, M. W. M., Steen, T., Bos, C. v. d., and Geenen, M. The think aloud method: a guide to user interface design. *International Journal of Medical Informatics 73*, 11–12 (2004), 781–795.

11. May, A. J., Ross, T., Bayer, S. H., and Tarkiainen, M. J. Pedestrian navigation aids: information requirements and design implications. *Personal Ubiquitous Comput. 7*, 6 (2003), 331–338.

12. Mehigan, T., and Pitt, I. Harnessing wireless technologies for campus navigation by blind students and visitors. *Computers Helping People with Special Needs* (2012), 67–74.

13. Mkpong-Ruffin, I., Murphy, A., Larkin, V., and Gilbert, J. E. *CAMPNAV: A Campus Navigation System For the Visually Impaired*. World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2006. AACE, Honolulu, Hawaii, USA, 2006.

14. Nielsen, J., Clemmensen, T., and Yssing, C. Getting access to what goes on in people's heads?: reflections on the think-aloud technique. In *Proceedings of the second Nordic conference on Human-computer interaction*, ACM (572033, 2002), 101–110.

15. Queensland University of Technology. QUT at a glance. Retrieved 10 September, 2013, from `http://www.qut.edu.au/about/the-university/qut-at-a-glance`.

16. Retscher, G. Pedestrian navigation systems and location-based services. In *3G Mobile Communication Technologies, 2004. 3G 2004. Fifth IEE International Conference on* (2004), 359–363.

17. Stark, A., Riebeck, M., and Kawalek, J. How to Design an Advanced Pedestrian Navigation System: Field Trial Results. In *Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, 2007. IDAACS 2007. 4th IEEE Workshop on* (2012), 690–694.

18. Tao, M., Gallagher, T., Li, B., Dempster, A. G., and Rizos, C. Indoor/Outdoor On Campus Navigation System. In *International Conference on Indoor Positioning and Indoor Navigation*, vol. 13 (2012), 15th.

19. Temple University. Temple ROUTE. Retrieved 15 March, 2013, from `http://temple.here2theresoftware.com`.

20. The University of Queensland. UQnav for iPhone, iPod touch and iPad on the iTunes App Store. Retrieved 22 March, 2013, from `https://itunes.apple.com/au/app/uqnav/id418832030?mt=8`.

21. The University of Sydney. Sydney Uni for iPhone, iPod touch and iPad on the iTunes App Store. Retrieved 22 March, 2013, from `https://itunes.apple.com/au/app/sydney-uni/id542003075?mt=8`.

22. TomTom. Car Navigation. Retrieved 3 August, 2011, from `http://www.tomtom.com/en_gb/products/car-navigation/index.jsp`.

23. University College London. UCL Campus Route Finder. Retrieved 25 February, 2013, from `http://crf.casa.ucl.ac.uk`.

24. Wireless Trondheim and Norwegian University of Science and Technology. CampusGuiden.no. Retrieved 17 March, 2013, from `http://www.campusguiden.no/?lang=english`.

25. Workman, R., Gschwender, A., and Chan, J. L. Campus google map applications. *EB/OL* (2005).