POINT OF INTEREST AWARENESS USING INDOOR POSITIONING WITH A MOBILE PHONE

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Abstract: Although location based applications have been gaining popularity, most positioning devices do not work when in an indoor environment, hindering the development of both mixed and indoor location based applications. In this paper we present a point of interest aware application that shows information to the user that is dependent on his indoor location. To be able to detect the user's position, we propose a technique, based on the detection of footsteps, and the direction in which they were taken, to be able to calculate the position of the user inside a building. To improve the accuracy of the system, we use information about the buildings floor plan to create a graph that can be used to correct invalid movements.

1 INTRODUCTION

Global positioning devices (GPS) are becoming progressively more common in new mobile devices and, for this reason, the real time information about the location of users has become widely used in an extensive range of location based applications, as diverse as car navigation, city guides or geocaching applications.

Indoor location based services can be used to show relevant information about the users' location and help them navigate in an unknown building, or track users with special needs, children, or inmates inside a prison compound. The indoor location could also be used to allow emergency services to explore unknown areas in an easier and more efficient way (Pahlavan, Li and Mäkelä, 2002; Jensen, Kruse and Wendholt, 2009).

Despite being reliable and precise while in the open, GPS devices need to be able to view a large portion of the sky to be able to correctly calculate the device's position. This limitation has the consequence of rendering the GPS useless while indoors. Furthermore, alternative positioning systems like the ones that use GSM or mobile phone tracking do not have high enough accuracy to be able to correctly identify a position inside a building. Consequently, these restrictions hinder the development of location based applications that also focus on indoor use (Beauregard and Haas, 2006).

Our research is mainly focused on location based services in mixed environments and the study of visual adaptations to different contexts. We have previously explored outdoor location based applications, namely a point of interest visualization application (Carmo, Afonso, Pombinho and Vaz, 2008) where information is presented over a map of the region the user is currently at, and a location and orientation based application that shows information about points of interest that lie in the direction the user is aiming the device at (Pombinho, Carmo, Afonso and Aguiar). Hereafter, to allow the exploration of indoor locations and enable us to proceed our research in mixed environments, we need to be able to obtain the position of the user while inside a building.

Our goal is to develop an application that enables the exploration of buildings unknown to the user and also allow him to obtain information about the different points of interest that may exist, inside the building, near the position the user is currently at. To achieve this, we first have to be able to correctly estimate the user's indoor position. To avoid the limitations of positioning systems like the GPS that, as referred, do not work indoors, or the use of expensive and complex physical infrastructures installed in each building, we present an algorithm that allows the position of users inside a building to be inferred from the movement done by the user. To achieve this goal we use a mobile device with an integrated accelerometer to detect when the users takes a footstep, and a digital compass to determine the direction of each footstep. Using this information and the knowledge of the buildings floor plan we can calculate with an acceptable accuracy the indoor location of the user.

In the next section we will describe the current indoor positioning technologies and techniques. In section 3 our proposed positioning algorithms and techniques are explained. In section 4, we present the developed point of interest location aware application prototype. In section 5, we present the user experiments that were carried out. Finally, in section 6 we conclude and point out future work.

2 INDOOR POSITIONING TECHNOLOGIES

There are already some works that explore indoor positioning mechanisms. Most of these works can be divided in three main categories: techniques that use physical infrastructures installed on the buildings, explicitly for indoor positioning; techniques that use existing Wi-Fi networks; and the techniques that use sensors installed in the mobile device or the user himself.

2.1 Infrastructures Installed for Indoor Positioning

There are several diverse approaches that use transmitters of some kind, installed on the buildings, and corresponding receivers, carried by the user.

Hiyama et al. (2005) propose a museum guiding systems using infrared (IR) transmitters installed at each 1 meter interval on the ceiling of the Japanese National Science Museum in Tokyo, and an IR receiver embedded in a monaural headphone connected to a museum guiding device. The infrared transmitters cover overlapping areas, allowing the receiver to recognize that the user is standing between two specific transmitters.

Lim and Zhang (2006) propose a similar indoor positioning method but, instead of IR transmitters, use Radio Frequency Identification (RFID) tags distributed around an area, enabling a user carrying an RFID reader to get, at one time, more than one RFID, and estimate his physical location. From the experiments made, the authors conclude that this approach is capable of an estimation error of only 1 meter.

Ghiani, Paternó, Santoro and Spano (2009) implemented a mobile guide in the Carrara Marble Museum and in the Calci Museum of Natural History, where active RFID Beacon tags are placed near the museum exhibits. The RFID reader carried by the user allows the application to identify which beacons are visible and, by analyzing their RSSI (Received Signal Strength Indication) calculate which of these the nearest one is.

Xu et al. (2009) propose a two step tracking procedure. In the first step, a beacon-correlation algorithm uses RSSI information from all the detected beacon nodes to identify a wider area where the user is. In the next step, a shadowing-grid localization algorithm, using only the RSSI information from the beacons present in the identified area, is used to identify the accurate location of the user.

Ikeda et al. (2008) propose the use of a wireless sensor network using low power VHF radio to provide indoor positioning services. This system was implemented on the Yokohama Landmark Plaza in Japan and uses a Smartphone that integrates a node that receives beacon signals and processes them to detect the user's position and trajectories.

The PhoneGuide system (Bruns, Brombach, Zeidler and Bimber, 2007) is a museum guidance system that uses Bluetooth emitters in each exhibit, which are identified by the user's receiver. This does not allow sufficient accuracy to differentiate individual objects located within the signal range. However it does allow the system to know which exhibits are currently visible and, with this information, to use the pictures captured by the camera and compare them to the stored pictures of the currently visible objects, to be able to recognize to which one the user is looking at.

Rainer Mautz (2009) studied some recent indoor positioning systems that are capable of achieving cm-level accuracy. In his paper, he explores: the iGPS system (Krautschneider, 2006) that uses a transmitter of rotating fan-shaped infrared laser planes that is capable of a mm-level accuracy; the Locata System (Barnes, Rizos, Kanli and Pahwa, 2005) which is a positioning system that uses radio signals transmitted in the 2.4 GHz band, to be able to penetrate the inside of buildings, by transceivers placed within a range of several hundred meters up to several kilometres and with a sub cm precision; and the Cricket (Priyantha, 2006), Active Bat (Hazas and Hopper, 2006), and Dolphin system (Fukuju, Minami, Morikawa and Aoyama, 2003), which are ultrasonic positioning systems that have beacons emitting both ultrasonic pulses and radio frequency messages, and receivers that can use the difference in the arrival of both the signals to calculate de distance from each beacon and triangulate their position.

Kalkusch et al. (2002) present a mobile augmented reality application where the user has a helmet with a mounted camera that detects and tracks well known markers, previously scattered around the environment. This tracking allows the system to identify the position and orientation of the user.

2.2 Indoor Positioning Using Existing Wi-Fi Networks

Several systems have explored the use of Wi-Fi wireless network access points.

Bahl and Padmanabhan (2000) developed the RADAR system, which operates by identifying and processing the signal strength information of multiple base stations that are positioned in a way to provide overlapping coverage, and triangulate the position of the user with an accuracy of a few meters.

Kitasuka, Nakanishi and Fukuda (2003) propose the WiPS system. This system is similar to the previous one, however, instead of only using information from the wireless LAN access points, the WiPS system also communicates with the neighbouring WiPS terminals and uses information obtained from them to be able to increase its accuracy.

There are also commercial systems that explore Wi-Fi Networks to provide indoor positioning. The Ekahau Real Time Location System (RLTS) (Ekahau, 2010) uses the existing Wi-Fi Networks to provide sub room, room, floor or building level accuracy, depending on the number of access points available. Nokia are also currently developing an experimental indoor positioning service at the Kamppi Shopping Center in Helsinki, Finland, that uses Wireless LAN (Nokia, 2009).

2.3 Infrastructure Free Indoor Positioning

Kourogi et al. (2009) use an approach where sensors are placed on the user's waist, to detect walking stance and velocity. This approach is then enhanced by the use of surveillance cameras to estimate the walking parameters.

Stéphane Beauregard (2008) focuses on the indoor positioning of emergency first responders. Shoe mounted sensors are used and a foot-inertial pedestrian dead reckoning approach is proposed to detect the displacement made by the foot in each footstep and consequently the total displacement made by the user. The placement of the sensor on the shoes instead of other body areas allows better results to be achieved when in the presence of irregular walking patterns or sharp turns typical of rescue missions.

Jiménez, Seco, Prieto and Guevara (2010) also use shoe mounted sensors and developed the INS-EKF-ZUPT framework to detect the position and attitude of a person while walking. They also employ a stance detection algorithm and several methods for heading drift reduction.

Commercially, the Nike + iPod Pedometer System (Nike, 2010) that has sensors placed in the user's shoes allows him to hear useful information through his iPod about the exercise he is currently doing.

Glanzer, Bernoulli, Wiessflecker and Walder (2009) present an inertial pedestrian navigation system that uses a low-cost micro-electro-mechanical-system (MEMS) based Inertial Measurement Unit consisting of a three-axis accelerometer, a three-axis gyroscope, a three-axis magnetometer, a temperature sensor, an A/D converter and a microcontroller. From the data obtained from these sensors, an integration of the acceleration values is done to obtain changes in position and attitude, and calculate the final position of the user.

Köhler et al. (2007) have developed a prototype for indoor positioning in small rooms, that uses a compass, camera and grid projector. The system projects a grid pattern into the environment to try and determine the location of the planes (corresponding to the walls) and intersections (corresponding to the corners). If the system can detect three orthogonal planes, for example two walls and a ceiling, it can find its position and orientation relative to that particular corner and, by using a compass, find which particular corner it is and consequently the relative position inside the building.

Randell, Djiallis and Muller (2003) compare different pedestrian dead reckoning techniques and the use of different sensors that can be used to get accurate measurements. They explored four different case studies and were able to obtain accuracies of the same order as a basic GPS receiver.

Ladstätter, Luley, Almer and Paletta (2010) use a sensor placed in the pocket of the user to detect shifts in acceleration and use the Weinberg Expression to adjust the thresholds dynamically. They have determined that the accuracy of the technique is reliable for walking speed higher than 1 m/s, but has too many false positives when used at slow speeds.

Very recently, some preliminary works have started to appear that focus only on the use of sensors integrated in the mobile devices. Serra, Carboni and Marotto (2010) present the early developments of an indoor navigation system that uses the device's accelerometer, compass, camera and internet connectivity. Despite using only the sensor of the device, the proposed application uses datamatrix drawn in maps scattered in the buildings to obtain the buildings map and the starting position.

Some experiments have also been made recently, to do an early evaluation of the accuracy of these types of techniques. Dekel and Schiller (2010) present an ongoing series of tests that explore indoor navigation with un-augmented smart phones. They were able to obtain an accuracy of more than 90% on the detection of the distance travelled.

3 INDOOR POSITIONING

Despite providing some solutions for the indoor positioning problem, the works presented in the previous section are all either based on the existence of a physical infrastructure in each building, or the need of external sensors that are placed, for example, on the user's shoes or waist. These sensors are a potential limitation to the natural movement of the user or the practicability of the system. Furthermore, some of the presented systems require very expensive equipments and others, although using relatively cheap beacons, require the installation of a large number of them to be able to obtain good accuracy.

Since our aim is to develop mixed environment (indoor and outdoor) adaptive visualization applications, our goal is to develop an approach that does not need external sensors, beyond those integrated in the mobile device, and that can be used in buildings with no physical infrastructure installed. Furthermore, since the user is holding the mobile device in his hand, we want an approach that does not hinder the users hand movements, allowing him to retain some of the freedom of movement they usually have when using a mobile device.

In the next subsections we will describe our proposed approach. It comprises step detection and the identification of the user's position in a floor plane graph.

3.1 Step Detection Algorithm

We use a 3-axis accelerometer integrated in the mobile phone to capture, in real time, the accelerations that the device is being subjected to.

When in a standing / resting stance, the only acceleration that is present in the mobile device is gravity. If we consider the mobile device to be perpendicular to the floor plane, the X and Z axis would be measuring no acceleration, and the vertical Y-axis would be measuring the gravity, with a value of approximately -9.8 $m.s^{-2}$. Since the users can freely tilt and rotate the mobile device, we have no prior knowledge of which accelerometer axis is, at a given point, measuring the vertical acceleration. For this reason, despite potentially adding some noise, we have chosen to analyze the resulting acceleration vector norm, instead of analyzing each axis separately.

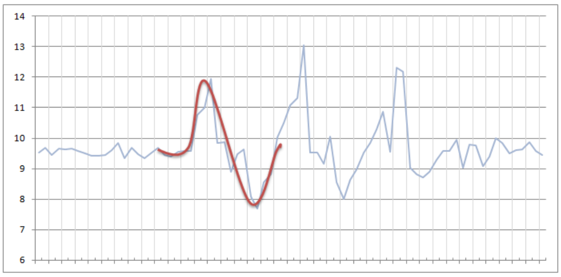

Figure 1: Shifts in acceleration vector norm while walking, represented in a blue thin line. The red thicker line shows a single step pattern.

When walking, the user will, not only, apply a forward acceleration but also, with a greater magnitude, alternatively apply a vertical upward acceleration followed by a vertical downward one. Figure 1 shows an example of the acceleration changes due to the user walking three steps.

We have defined four parameters that are used to detect a footstep:

- a peak amplitude λp that represents the minimum positive shift in acceleration caused by a footstep,
- a trough amplitude λt that represents the minimum negative shift in acceleration caused by a footstep,
- a minimum time interval Δtmin that needs to go by before completing the footstep pattern,
- a maximum time interval Δtmax that cannot be exceeded for the footstep pattern to be detected.

All of these parameters can be changed inside the application in real time. The description of the step detection algorithm is as follows:

```
Step 1: calculate acceleration norm: a

Step 2: if(a > λp)
   start timer t
   start pattern detection

Step 3: while(t < Δtmin)
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```
   if(pattern detected)
      discard footstep
      stop pattern detection

Step 4: while(t > Δtmin AND t < Δtmax)
   if(pattern detected AND a < λt)
      footstep detected

Step 5: if(t > Δtmax)
   discard footstep
```

The step detection algorithm works by constantly checking if the current acceleration is greater than λ_p. When that happens, the application starts to check if the footstep pattern is occurring. If a sudden shift in acceleration occurs in less that Δt_{min}, we assume that it was caused by another movement and the step is discarded. If the pattern occurs in more time than Δt_{min} but less than Δt_{max}, and it reaches λ_t creating a pattern similar to the one shown previously, a step is recorded along with the current orientation, which is obtained from the digital compass. If after Δt_{max} we still have not detected the footstep pattern, the step is discarded.

To be able to identify the location of the user inside a building, we use the last known latitude and longitude obtained from the GPS as the initial location of the algorithm. Afterwards, as each step is detected, we use the orientation obtained from the device's digital compass and the defined average step length to calculate the displacement made. By adding all the displacements we can calculate the trajectory taken by the user inside the building and also his current location.

3.2 Floor Plan Graph and Position Correction

Although the algorithm described in the previous section can give an accurate positioning when used for short periods of time, it can accumulate a significant amount of error when used for longer periods of time. To minimize errors caused by steps that are not detected (false negatives), steps incorrectly detected (false positives), or errors in the step size, we make corrections to the position of the user using information about the building's floor plan.

We have chosen to represent the floor plan by the use of graphs, inspired by the works done by Stoffel, Schoder and Ohlbach (2008) and Yuan and Schneider (2010), in which the geometry of the buildings floor plan is used to define a graph of the possible paths a user can take.

We have opted to divide the floor plan in rectangular areas of different sizes, where transition areas (for example, doors) have the smallest size, and areas with no transitions (for example, long corridors with no doors) have the bigger areas. Each of these areas corresponds to a node in the graph.

Figure 2 shows, on the left, an original floor plan with the considered areas in red, and in the right the graph that was defined, with a node for each area.

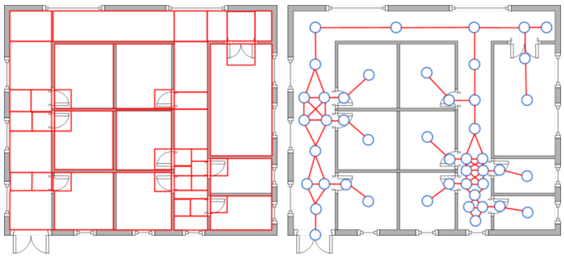

Figure 2: Definition of the floor plan graph.

The use of the graph allows calculating, with each step taken, the position of the user inside a certain node area. If at any time, the calculated position is outside the current node area, the system will verify if there is a valid transition from the current node to another node in the specified direction. If there is a valid transition, the system places the user on the next node and calculates his location in the new node area. If there is no valid transition in the recorded orientation (i.e. there is no direct path from the current node to the new one), the system searches for the nearest position where the detected movement would be valid and corrects the user position.

4 APPLICATION PROTOTYPE

Our goal is to develop a point of interest aware application that can enable a user to roam inside an unknown building (for example, a shopping mall or a university campus) and quickly obtain useful information. The application should aid the user in finding specific places and also to easily explore the building while obtaining information about the points of interest he is near to.

To test and evaluate our approach, we have developed a simple application prototype for a HTC Smartphone. We use the Smartphone's integrated accelerometer to obtain, in real time, the acceleration the device is being subjected to, and the digital compass, to obtain the orientation of the device.

To obtain information about the points of interest, we use a SQL Server database that contains data about the name, location and attributes of each point of interest. However, to illustrate the proposed concept, we have defined a simple floor plan composed of only nine different points of interest.

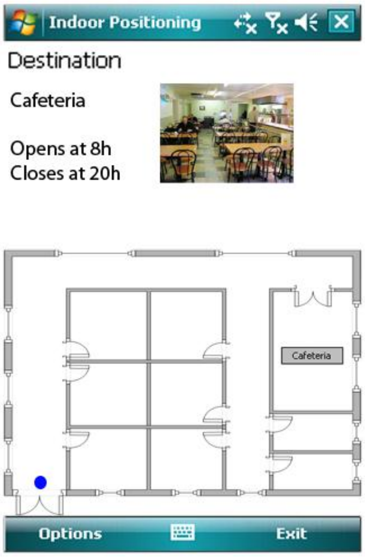

Figure 3: Prototype showing the desired destination.

The developed application has two main display modes. In the first mode, used to support a search task, if the user wants to search for a specific point of interest, he can select the "Select PoI" button from the "Options" menu and then search for the specific point of interest he wants to find (for example a certain store). When the user selects a point of interest, it will be highlighted in the building plan. Additionally, the available information about that point of interest will also be shown in the upper part of the interface (Figure 3).

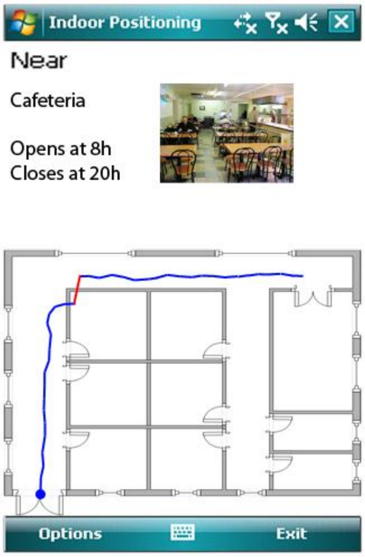

Figure 4: Prototype showing the path the user has taken.

The second mode is used to support an exploratory task. If the user does not select any point of interest, the application detects what areas the user is near to, and shows information about them in the upper part of the interface (Figure 4).

In our prototype, the main visualization area, in the bottom part of the interface, shows the path the users have taken drawn over the building plan and their current location marked by a blue circle (Figure 3). An example of path detection is shown in Figure 4. The position of the user and the path he has already taken is drawn in blue over the floor plan. If the user position is automatically corrected by the application, due to an invalid detected movement, the interface displays a thick red line to highlight the correction made.

5 USER EXPERIMENTS

To accurately calculate the position of the user inside a building, it is essential that we use adequate step detection parameters and also consider an accurate step size. To be able to obtain these values, we performed a set of experiments to allow us to understand the differences between the walking patterns and step size of a diverse set of users.

5.1 Procedure

At the start of the experiment, we asked each user their name, weight and height. Seven users performed our experiments, four were male and three female. They had diverse heights and weights, ranging from 160 cm to 180 cm and 65 kg to 81kg, respectively.

Afterwards, each user was asked to hold the mobile device in their hand and follow the instructions that were presented on the device's screen. For each experiment, the user's were given indications on the speed at which they were supposed to walk, and instructed to press a start button, walk ten steps and press the stop button.

The users were also instructed to stay on the spot where they stopped, to allow us to measure the distance they had travelled.

Each user was asked to carry out six tasks, three of them outdoors and the remaining three inside a shopping mall.

The users were first asked to walk in their normal walking speed when outdoors, then they were asked to walk slowly while observing the surrounding environment and, finally, they were asked to walk as if they were in a hurry to get somewhere. These tasks were then repeated while indoors, where the users were asked to walk in a normal speed, slowly while watching the shop windows, and quickly as if they were late.

Finally, we also conducted some experiments with the device secured on the user's waist to be able to obtain a control set with the device placed in a more stable position.

5.2 Results

After having concluded the experiments, the accelerometer logs, recorded by the mobile device, allowed us to create charts displaying the variation of the acceleration vector norm over time for each of the tasks conducted by each user.

Using these charts we were able to analyse the walking pattern of each user and determine, for each step, what the optimal detection patterns would be.

Regarding the λ_p and λ_t parameters, we wanted to understand if the minimum λ_p value and the maximum λ_t value were sufficiently different that they could be used as default values to detect all the steps. However, as can be seen in Figure 5, the values obtained are in fact very similar, and as consequence are not adequate for the algorithm.

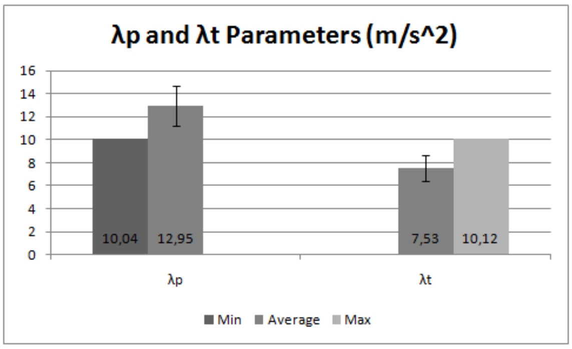

Figure 5: λ_p and λ_t acceleration parameters.

As an alternative, to obtain a set of values that can detect the majority of the steps, we can use the average and standard deviation for each parameter. As a result, the value of λ_p can be calculated by using the average (12.95) and subtracting the standard deviation (1.71). Similarly, the value of λ_t can be obtained by adding the standard deviation (1.11) to the average (7.53).

Regarding the time interval of the steps (Figure 6), the average time spent on a step (245 ms) and the relatively high standard deviation (99 ms) suggest that a similar approach can also be used to define the Δ_{tmin} as the subtraction of the standard deviation from the average and Δ_{tmax} as the sum.

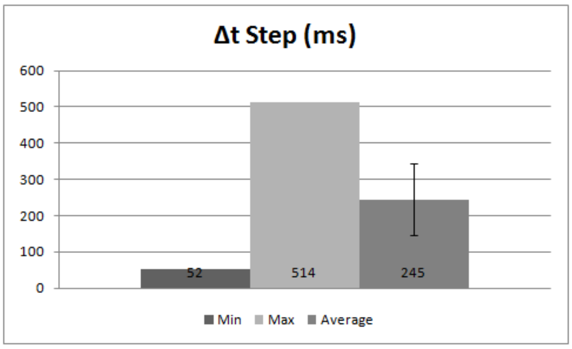

Figure 6: Time spent taking a step.

The values obtained allow us to detect the majority of the steps taken by the users, however, as can be seen by the standard deviation in the previous charts, there are significant differences in the way each user walks. For this reason, instead of using fixed parameter values, it would be better for an application to acquire information when the user is outside (where his movement can be detected by the GPS) to automatically calibrate the parameters.

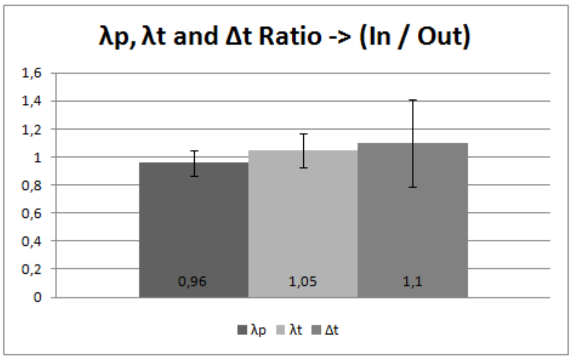

Figure 7: λ_p, λ_t and Δ_t indoor / outdoor ratios.

However, since the users do not move exactly the same when indoors as they do while on the outside, we also need to identify the ratio between the two types of movements. To achieve this, we calculated the ratio, for each user, between the indoor and outdoor experiments at the same speed. The average ratios are shown in Figure 7.

As important as detecting each step correctly, we also have to choose the right step size since, in the long run, it can originate a high amount of error. The average step size obtained from our experiments is 65 cm. However, there are significant variations depending on the speed of the movement and also if it is indoors or outdoors (Figure 8).

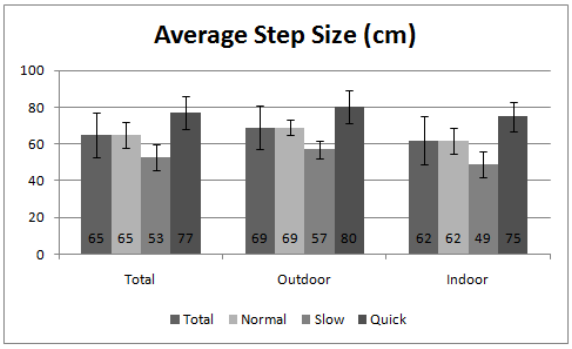

Figure 8: Average step size.

Despite the very diverse step lengths, when we consider the ratio between each pair of indoor / outdoor experiments, we obtain a ratio value that is fairly constant (0.9) and that is directly proportional to the speed of the user (Figure 9).

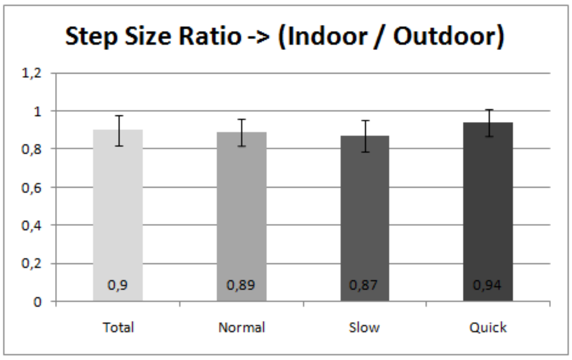

Figure 9: Step size indoor / outdoor ratio.

We also wanted to find the relation between the weight, height and step size of the user. To obtain the ratio, we calculated the (Height / Weight) / (Step Size). The average ratio calculated is 0.039 and is inversely proportional to the speed of the user (Figure 10).

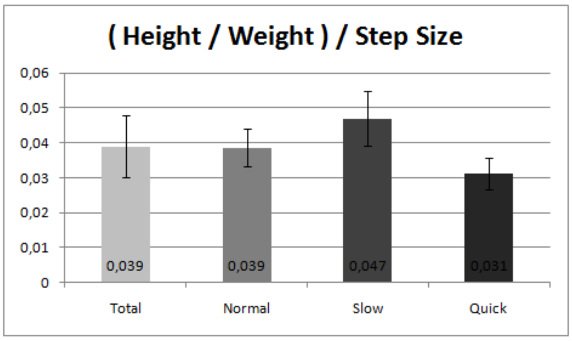

Figure 10: Height, weight and step size ratio.

Through the use of both the previous ratios and information obtained from the GPS, when the user is outdoors, it is possible to calculate with a low error the average step length for each particular user.

5.3 Evaluation

To understand if the proposed approach was valid, we conducted a small evaluation phase. This phase had the goal of determining the accuracy of the step detection algorithm.

Using information from the previous experiments we calculated, for each user, their optimal step detection parameters. After calibrating the application, we asked the users to walk 50 steps holding the mobile device in their hand and when they stopped recorded how many steps the application had detected. Each user conducted this evaluation three times.

On average, the algorithm detected 47 steps of the 50 (standard deviation = 2.5). Although the number of steps detected can, in the long run, be responsible for a high error, we believe that it can be minimized through the use of the floor plan graph position correction.

6 CONCLUSIONS AND FUTURE WORK

In this paper, we have presented a point of interest aware application that uses the information about the user's indoor location to display information about the points of interest that exist in the vicinity of the user. To be able to correctly identify the position of the user, we have proposed an indoor positioning method that does not need previously installed physical infrastructures in a building. Furthermore, this approach does not need external sensors, avoiding the restriction of the user's natural movements when using a mobile device and walking indoors.

We have performed some user experiments that allowed us obtain valuable data about the differences in the step patterns originated from a diverse set of users. This knowledge can give us the insight on what the best default step detection parameter values are, and also help us in implementing an automatic calibration of these values. A particularly important parameter, which can cause a high accumulated error, and should thus be automatically adjusted, is the step size, since it varies not only between different users, but also depends on the speed and way the user is moving. Since our aim is to use this algorithm in mixed environment visualization applications, one solution is to use information from the GPS when the user is outdoors.

Although there is still work to be done to be able to use this techniques, in a way they can be accurate with a diverse group of users, and in complex environments, the tests that we have done so far indicate that it is a valid approach.

We intend, in the future, to more precisely evaluate the precision of the algorithm, taking into account the position correction using the floor plan graph. We also intend to test more complex buildings floor plans, and consequently the detection of footsteps when going up and down a set of stairs, and the use of escalators and elevators.

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