Journal of Assistive Technologies

Indoor navigation with smart phone IMU for the visually impaired in university buildings

Jesus Victor Zegarra Flores Laurence Rasseneur Rodrigue Galani Fabienne Rakitic René Farcy

Peer-reviewed paper

Indoor navigation with smart phone IMU for the visually impaired in university buildings

Jesus Victor Zegarra Flores, Laurence Rasseneur, Rodrigue Galani, Fabienne Rakitic and René Farcy

Jesus Victor Zegarra Flores is a Research Scientist at the Faculté des Sciences du Sport, Université de Strasbourg, Strasbourg, France.
Laurence Rasseneur is based at the Faculté des Sciences du Sport, Université de Strasbourg, Strasbourg, France.
Rodrigue Galani is based at the Centre de Culture Numérique-DUN, Université de Strasbourg, Strasbourg, France.
Fabienne Rakitic is based at the SVU-Mission Handicap, Université de Strasbourg, Strasbourg, France.
René Farcy is a Professor at the Laboratoire Aimé Cotton, Université Paris Sud, Orsay, France.

Received 27 May 2015
Revised 26 August 2015
Accepted 31 August 2015

The authors would like to thank the University of Strasbourg for supporting this research through the "Investiment d'avenir" programme (excellence initiative: IdEx). The authors would also like to thank Lionel Auffray from the Fluids, Automatic and Thermal Systems Laboratory for his help in the hardware development of the first prototypes of the IMUs (inertial measurement units) using 3D printing at the beginning of this work when IMU integrated in smart phones were not efficient enough.

Abstract

Purpose – *The purpose of this paper is to design and test effective indoor navigation solutions for visually impaired people in situations where GPS, bluetooth or Wi-Fi signals are unavailable. The authors use the inertial measurement units (IMU), the compass and the barometer of a smart phone.*

Design/methodology/approach – *The authors have used commercial Android smart phones with IMU, compass and barometer to record a path and to give navigation instructions in an adapted way using a mobility-specific vocabulary. The method proposed is to save paths taking into account different indoor waypoints such as the stairs (change from one floor to another) and the change of direction of the trajectory of the path (e.g. one-fourth turn right or left), recording data from the IMU sensor's, compass and barometer of the smart phone. Having this information and the characteristics of the each segment (distance, azimuth to the north and pressure) of the path, it is possible to provide functional navigation guidance to the visually impaired subject. Three different visually impaired people (one partially sighted and two fully blind) and three sighted people have tested the paths. The efficiency of the navigation is analyzed in terms of distance and time using the comparison between blind and sighted people.*

Findings – *The main finding is that it is possible to guide visually impaired people some hundreds of meters just using the sensors of a smart phone under certain conditions: the visually impaired person has to understand the guidance instructions and respect some strategies (e.g. not to walk diagonally across vast spaces). Additionally it is observed that the visually impaired participants walked distances, which are not much different to the optimal values. On the other hand; because of their hesitations using their white cane to find free paths, they take in some cases 50 percent more time to arrive (for a few minutes path, this time is not critical and even more efficient than looking for a guide). One thing to highlight is that even with this hesitation, the subjects arrived to the final destination.*

Originality/value – *This paper demonstrates how an IMU coupled to a compass and a barometer from a Smart Phone employing a spoken mobility language (e.g. next corridor to the left; at the end of the stairs turn right, turn left, etc.) can guide visually impaired people inside buildings.*

Keywords *IMU, Barometer, Indoor navigation, Smart phone, University buildings, Visually impaired person*

Paper type *Research paper*

1. Introduction

A navigation system is a very important tool for improving the autonomy of visually impaired people. There are many places in which visually impaired people could improve their autonomy, for example, subway stations, commercial centers, hospitals, university's buildings, campuses, etc. The GPS system is widely used for outdoor navigation. On the other hand, for the case of indoor navigation where GPS signal is not available, studies have explored Wi-Fi, bluetooth or ultra wideband beacons that can help to localize one person in the indoor area (Mahiddin *et al.*, 2013; Evennou and Marx, 2005; Feldmann *et al.*, 2003; Fischer *et al.*, 2004; Fontanna, 2001;

Herrmann *et al.*, 2010). However, these beacons have to be placed in the infrastructure of the buildings, increasing the cost of implementation. Another way of indoor positioning is the use of dead reckoning (estimation of a position from a known position using sensors like barometers, accelerometers, gyrometers and compasses).

In this paper, the authors are going to describe a method to save paths taking into account different indoor waypoints such as the stairs (change from one floor to another) and the change of direction of a path (e.g. one-fourth turn right or left), recording data from the inertial measurement unit (IMU) sensor's, compass and barometer of the smart phone. Additionally, an indoor navigation system to guide the visually impaired is presented. The objective is to show the possibilities to enable the visually impaired people navigate in indoor places (university buildings) using low cost IMU sensors (IMU which come in commercial smart phones), compass and barometers without adding any physical structure (beacons) in the place.

The paper is organized as follows: Section 2 provides the discussion about the current state of art of the technology for indoor positioning and navigation. Section 3 describes the operation of the system design taking into consideration the possibilities and limitations of the different sensors used. In Section 4, it is described the testing set up and the different paths tested in the "PATIO building". In Section 5, it is shown the different results and Section 6 gives the conclusion and the future work.

2. Related work

The current state of the art of other studies, to deliver indoor positioning and navigation, relies on the use of beacon-based systems (Wi-Fi, bluetooth, ultra wideband radio technology beacons and the RFID tags) or dead reckoning systems IMU. It can also be a combination of the both systems mentioned before.

In the case of the beacon's systems, there are the Wi-Fi access points (Mahiddin *et al.*, 2013; Evennou and Marx, 2005), Bluetooth beacons (Feldmann *et al.*, 2003; Fischer *et al.*, 2004) or ultra wideband radio technology beacons (Fontanna, 2001; Herrmann *et al.*, 2010) which are placed in the building or the indoor places for calculating an absolute position of the person who carries a receiver (all tables and figures can be found at https://bitbucket.org/jeszeg/figures-and-tables-article-indoor-navigation-with-smart-phone/downloads) (see Figure 1). For the case of the Wi-Fi and bluetooth, the main drawback is that the precision might not be good enough because the signals of every beacon can rebound on the walls or on people in the place giving uncertainty.

On the other hand, for dead reckoning, the positioning is estimated from different sensors (accelerometer, gyrometer and compass) from a known position calculated by other ways (e.g. GPS). The main problem about dead reckoning is that the position error increases at every measure of new position (Groves, 2008). This is why it is used sometimes in conjunction with, for example, RFID tags for updating the current position but it is then necessary to have the tags in the place (House *et al.*, 2011). IMU sensors have also been used for facilitating human-machine interactions, for example, to recognize involuntary motions in terms of time, frequency and range of motions for people with cerebral palsy (Raya *et al.*, 2012). Another investigation highlight the use of the IMU placed on the foot to determine the running kinematics of the ankles of subjects (Low *et al.*, 2015).

The authors have not used the "Kalman filter", which has been widely studied by the researchers for the GPS-inertial navigation (Hesch and Roumeliotis, 2007). The authors want to propose new methods and algorithms for "dead reckoning" to approach indoor navigation solutions for visually impaired people. These methods combine the low cost inertial sensor's information from the smart phone with saved optimal navigation path data (originating from the same sensors) to generate a reliable indoor navigation in some hundreds of meters without putting any beacons or RFID tags in the place. The smart phone can be used hand-held, put in a shirt pocket or belt mounted. The main idea is that the visually impaired person can be guided from one room door to another room door or main entrance.

3. The operation of the system design

During the experiment, it was observed that when the visually impaired subjects were asked to keep the smart phone hand-held horizontally, most of the time, they had the tendency to keep the smart phone diagonally. On the other hand, when they use the smart phone hand-held vertically, it was easier for them to keep it in that position for long time. To keep the smart phone in one position is very important in order not to have problems when obtaining the north azimuth in both the recording and the navigation program. For these reasons, we have programmed two different ways of using the smart phone hand-held (see figure 2) for having more possibilities to adapt the position of the Smart Phone to the user.

In this part, we will describe how an indoor path file is generated and the characteristics of the navigation for the visually impaired person that includes the mobility language indications.

3.1 Generating the indoor route

If the plan of the building is not available, it is necessary to create an accessible path for the visually impaired person. To do this, an application has been programmed "the path recording program" that will save the characteristics of every segment of the total trajectory. The user will indicate different "transitions" (that indicate the beginning of a segment or the end of a segment) as waypoints. The transitions selected are, the change of the corridor to the right or to the left (generally one-fourth turn right or left), the beginning and the end of the stairs. The number of transitions that the path includes will indicate the difficulty of every path. Indications, such as, follow the right wall (mobility language vocabulary) or points of interests (nursery, "mission handicap" desk, etc.), can also be saved by typing or using speech recognition in every segment. The characteristics of the segment are important in order to describe the trajectory of the path.

The characteristics of a segment (represented between two transitions) are: the distance represented by the number of steps, the average pressure and the north azimuth of the segment, the step in the segment at which one eventual point of interest is saved (e.g. the nursery, XML file, see figure 3). In this example, it is presented a path with three segments, at the segment 0, the user has done 17 steps with 270° of north azimuth average and 991.62 hPa of average pressure. At the end of the segment, the person has turned right (end of segment 0 and also the beginning of segment 1). During the segment 1, he walks doing 20 steps in the direction of 359° north azimuth average. In this segment, at the step number 10, the nursery was declared as a point of interest (found on the right). At the end of the second segment, there is the transition, "the beginning of the stair," which represents the beginning of the segment 2.

The Android interface and the functions of the buttons are described in figure 4. The "start to memorize the segment" ("Démarrer l'enregistrement du segment") button; allows us to start the recording, after that the person starts to walk in the direction of the first segment, once the person arrives at the end of the segment, the user clicks on the "end of the segment and transition" ("Fin segment et transition") button and another submenu appears (figure 4 on the right). For example, it can be the beginning of the stairs, the end of the stairs, to turn to the right or the left. After selecting the transition, we click on "start to memorize the segment" ("Démarrer l'enregistrement du segment") button again and we continue with the same process for the second segment and so on. The button "end of the trajectory" ("Finaliser le trajet") is selected when we have finished the last segment of the trajectory to create the XML file with the information to be used by the navigation application.

Distance estimation. The distance can be estimated by using the accelerometer, in this case it uses the vertical acceleration, which has bigger amplitudes than the horizontal acceleration and is less dependent on the way of walking of the person, to count the number of steps (pedometer basis, see figure 5). In order to have the average step length, the person has to walk a 20 meters distance (distance divided by the number of steps). This information is an input in the parameters of the program. In figure 5, we have shown the vertical acceleration, and the detection of each peak is one step. After, we multiply the number of steps by the average step length in order to obtain the distance. The step length is a reliable variable, repeating a 100 meters straight line walk, with sighted or blind people; usually the error is plus-minus one step.

Altitude estimation. The pressure sensor used is the LPS331AP. The function of the pressure sensor is as follows: if the person goes down the stairs, the pressure increases. Inversely, if the person goes up the stairs, the pressure decreases (see figure 6). In order to translate pressure differences to altitude differences in meters, the difference of pressure has been multiplied by one meter/0.1 hPa (value calculated during the experiment, a fixed value of seven meters of altitude divided by the difference of pressure detected). The main limitation of this sensor is that a difference of just three or four stairs is obscured by the noise of the sensor; to meaningfully detect altitude differences about ten stairs have to be traversed.

North azimuth estimation. In order to decrease the variation of the azimuth caused by the magnetic field perturbations of the place in a segment, the average of the azimuth of the segment is calculated. The program senses all the magnetic fields perturbation in the three axes of the compass in a segment and it obtains the azimuth employing an average.

Cartography of a path. In figure 7, the cartography of a path done with the IMU is shown. The transitions are: T1: turn right, T2: turn left, T3: beginning of stairs to go up, T4: end of stairs T5: turn right and T6: end of the path.

3.2 Indoor navigation

The authors will describe the "navigation program" that uses the previously saved information. The strategy for the indoor navigation is based on the confirmation of the transition and the characteristics of each segment of the path. For example, the visually impaired person will receive a message (seven meters before if the segment is bigger than seven meters) to get ready to turn right. If the segment is less than seven meters, the message will be delivered just if the orientation of the person is in concordance with the orientation of the small segment for at least two seconds. In order to receive the "OK vocal confirmation," he has to turn right and to take the right orientation (coherence analysis between the north azimuth saved and the north azimuth obtained during the navigation); additionally, the person has to walk in the right direction describing a straight line. In this way a "turn right" coming from a hesitation attitude or simply from a person stopping and turning to talk to somebody will not be considered. The next corridor represents a new segment (figure 8). The straight line is calculated with the help of the accelerometer and the gyroscope. In every step detected, the information of the gyroscope angle is saved, if the values of the difference of the gyroscope's values of six steps with the first gyroscope value is less than 30° in every case, it is considered that the person is in a straight line. The device will confirm and it will say "ok" additionally to the next information to do. Once the ok confirmation is done, the distance estimation is reset to 0 to estimate the new distance of the new segment.

For the case of going down or up the stairs, after passing 1.5 meters (approximately ten stairs), the system will say "Ok, continue to going down or up the stairs." When arriving to the end of the stairs segment, it will say "At the end of the stairs," and the information of the next action to do (for instance: turn left and continue).

First of all, the device will indicate the position to start the navigation; it can be, for example, at the "door 313" or at the main entrance of a building. The navigation interface (figure 9) is as simple as possible and come with four buttons. The first button "confirmation of the departure" (confirmer depart) allows the user to start the navigation, but only if their orientation is in concordance with the direction of the first segment. Otherwise it will say, for example: "starting direction to six o'clock," as a consequence, the person has to turn back and confirm again the departure.

The second button "listen to the last information given" ("Réecouter dernier message") allows the person to listen to the last information given by the application; this is for a situation such as the user could not listen to the information clearly (students talking loudly and perturbing the user).

The third button "go back" (retour) goes back to a previous menu where you can select one destination from one list of trajectories memorized. Finally, the "quit" (quitter) button closes the application.

3.3 Detecting errors

While the visually impaired person is navigating and following the instructions, it is necessary to take into account the possible mistakes they can make, for example, if the person instead of turning right and continuing, turns left and continue. The system will prompt the user saying "wrong direction taken, turn back to continue." In figure 10, the line in green represents the right direction to take in different path configurations; in contrast, the line in red (dashed lines) represents the wrong direction the visually impaired might probably take and the instruction given by the system detecting the error.

4. System testing set up

4.1 Subjects

All the visually impaired subjects selected were students volunteers from the university. In order to validate the level of mobility of the visually impaired volunteers, a mobility and orientation instructor has evaluated them to know if they have the minimum requirements for using the application which are having the notion of "left" and "right", knowing the clockwise guidance (12 o'clock means go straight, three o'clock means turn right, etc.) and to have good skills at using the white cane.

Two paths were selected for training the visually impaired and getting familiar with the instructions of the device. The training lasted between 20 and 50 minutes depending on if they are used to the vocabulary or the different functions of the application.

The paths, selected for the final tests, were between 50 and 100 meters long going through corridors and passing from one floor to another. A sighted person knowing the use of the application recorded the three test paths in the "PATIO building" and the navigation instructions were tested and approved by a person knowing the mobility language before testing with the visually impaired people. The visually impaired subjects did not know the place before going to run the tests.

The three paths are shown in figure 11: the first path starts from the PATIO main entrance at the ground floor where, first of all, the subject has to go up the stairs to pass to the first floor. At the end of the stairs, they have to turn left and continue in a straight line until arriving at the door of the Amphi 5 (line in green). The second path will start form the door of Amphi 5 to go to the door of classroom 3201 on the second floor (line in orange). Finally, the third path starts form the door 3201 to go to the initial position, the entrance of the building (line in blue).

In case of failure in arriving at the destination at the first try, it was possible to try two more times, repeating the path from the beginning. Success in arriving at the right destination could be observed on the first, second or third try. The parameters obtained were the time the person lasted to arrive to the destination and the number of steps in case of success.

Additionally, three sighted individuals have also walked the three paths in order to allow the authors to compare the efficiency of the system to sighted navigation on the route. The parameters obtained are also the time the person lasted to arrive to the destination and the number of steps.

The average step length of every subject (input in the parameters of the application) was obtained dividing a 20 meters distance in a straight line by the number of steps.

5. Results

All the tests were done in real conditions (corridors or halls not necessarily empty, see Figure 12). The results of the visually impaired subjects are presented in Table I. Moreover, the results with the three sighted people are presented in Table II. Additionally, the efficiency of the route will be analyzed in this part.

In the tests with the visually impaired subjects, all the users arrived to the final destination in the first or second try. One of the things observed was the high concentration needed for someone not familiar with this form of guiding instructions. When the subject made a mistake and the system stopped working because it was disoriented, the authors explained to the subject the cause of the problem and they started again the navigation test from the beginning.

One problem observed was the case of the third subject who did not make a straight line when walking and as her usual practice follow the walls. In the first test, she followed the first wall in diagonal and arrived to the door of the Amphi 7 and because she arrived to a door, she thought the navigation was finished. The information "go along in the middle of the corridor" was added to avoid this problem and when the person is arriving to the door of the Amphi 5, another information "follow the left wall until arriving at the door Amphi 5" was also added.

Table II shows the navigation time and the number of steps of each sighted subject who has done the three paths. All of them arrived in the first try.

5.1 Efficiency of the route

Once the destination is reached, the first criterion to describe the efficiency of the route is the distance (trajectory represented by the number of steps multiplied by the average step length) and the second criterion is the time needed to arrive to the destination. In order to analyze the efficiency of the route, the optimal distance and time is taken as the average of the distance and time done by the sighted people (reasonable not least because the distances and times of the sighted subjects were very similar). Taking this into consideration, it has also been calculated for every blind subject on each path, the ratio between the distance done and the optimal distance, the same for the time. Furthermore in Figure 13 can also be seen, the mean ratio and the standard deviation of the distance and time for the three paths for each visually impaired subject, the mean ratios (distance and time) are in blue and the standard deviation ratios are in red.

According to Figure 13, the authors can point out that the difference in the efficiency of the route (distance walked) between sighted and visually impaired people is very small. The path (visually impaired)/ path (sighted) is in average around 1.05, that is about 5 percent different. However, we can see that the time needed by the visually impaired is in average about 57 percent higher compared to the sighted people.

The mean ratio and standard deviation in time and distance of the subject 1, being partially sighted, do not have much difference with subject 3 who is a fully blind person. On the other hand, subject 2, who is a fully blind person, has more difficulties in time and distance. However, if we take into consideration that the subject 3 failed two paths in the first try (see Table I), we can say that she is faster but less reliable compared to subject 2 who arrived to all the destinations in the first try.

The most critical case is the second path for the visually impaired subjects; it is explained as the visually impaired subjects hesitate more to find the free paths. Specially, the second path for the second subject (the fully blind subject stopped and hesitated to look for the information with his white cane, doing small steps in different directions in locations in the path such as the corridors and the beginning of the stairs. The authors could say that the efficiency on time was not optimal; however, even with this kind of walking behavior the visually impaired arrived to the final destination independently. For paths of a few minutes, an additional time of 50 percent is not critical and more efficient than looking for another person to help.

6. Conclusions and future work

The partially sighted subject arrived to the final destinations faster and in the first try compared to the other two fully blind people. It is explained because of their residual vision; they can detect the corridors with less hesitation compared to the two other subjects.

Depending on the number of transitions in the path, the visually impaired subject (partial or fully) who arrives in the first try did not necessarily do longer distances. However, in some cases, they can take more time to arrive because they could hesitate (doing small steps) to find the corridors and the beginning of the stairs (for instance, second subject in the second path). Even with this kind of hesitation walking behavior, the visually impaired person can arrive to the final destination in a functional time justifying the use of the system.

We have shown the possibilities to save one navigation path file with the application and to use it to give instructions to guide the visually impaired. The guiding strategy proposed by the "recognition of each segment of the trajectory" seems to be accurate under the following conditions: the user has to be trained in order to understand the specific characteristics of the mobility language and the navigation. Additionally, the visually impaired person has to respect some strategies at walking like not to walk diagonally across vast spaces or not to follow walls if it is not indicated by the instructions.

Future improvement will include the automatic generation of paths, with the map of the building, from every classroom to another.

Another future improvement will test the paths with more visually impaired subjects in at least two different seasons in order to test the robustness of the algorithms (e.g. the robustness to detect the difference of altitude).

In the tests done, the application for "recording a path" was used by a sighted person knowing very well the use of the application. In the future tests, the visually impaired person will be taught of how to use the application for "recording a path" to analyze the possibility of the use of the application by the end users.

A more thorough research will be done in the case of the error recovery in order to have more possibilities to retake the navigation even when the system is disoriented. For a particular case, if the visually impaired student stops during the navigation to talk to another person for more than ten minutes and forgets the instructions to do. In this case a possibility to stop the navigation automatically or manually during the navigation will be programmed to retake the navigation from another departure point.

References

Evennou, F. and Marx, F. (2005), "Improving positioning capabilities for indoor environments with WiFi", The 14th IST Mobile & Wireless Communications Summit, Dresden.

Feldmann, S., Kyamakya, K., Zapater, A. and Lue, Z. (2003), "An indoor bluetooth-based positioning system: concept, implementation and experimental evaluation", *International Conference on Wireless Networks, June*, pp. 109-13.

Fischer, G., Dietrich, B. and Winkler, F. (2004), "Bluetooth indoor localization system", *Proceeding Workshop on Positioning, Navigation and Communication, March*, pp. 147-56.

Fontanna, R. (2011), "Advances in ultra wideband indoor geolocation system", Third IEEE Workshop on WLAN, Boston, MA, September, available at: www.cwins.wpi.edu/wlans01/proceedings/wlan53d.pdf

Groves, P.D. (2008), *Principe of GNNS, Inertialand Multisensor Integrated Navigation System*, Artech House, London, pp-6, 7, 340.

Herrmann, R., Sachs, J. and Bonitz, F. (2010), "On benefits and challenges of person localization using ultra-wideband sensors", *International Conference on Indoor Positioning and Indoor Navigation (IPIN), IEEE, September*, pp. 1-7.

Hesch, J.A. and Roumeliotis, S.I. (2007), "An indoor localization aid for the visually impaired", *IEEE International Conference on Robotics and Automation, IEEE April*, pp. 3545-51.

House, S., Connell, S., Milligan, I., Austin, D., Hayes, T.L. and Chiang, P. (2011), "Indoor localization using pedestrian dead reckoning updated with RFID-based fiducials", *Annual International Conference of the IEEE, Engineering in Medicine and Biology Society, EMBC, IEEE August*, pp. 7598-601.

Low, J.H., Lim, P.Y. and Yeow, C.H.H. (2015), "A wearable foot motion tracking sensor for outdoor running", in Colloud, F., Domalain, M. and Tony Monnet, T. (Eds), *33rd International Conference on Biomechanics in Sports, Poitiers, France, June 29-July 3 2015*, Equipment/Instrumentation.

Mahiddin, N.A., Madi, E.N., Dhalila, S., Hasan, E.F., Safie, S. and Safie, N. (2013), "User position detection in an indoor environment", *International Journal of Multimedia and Ubiquitous Engineering*, Vol. 8 No. 5, pp. 303-12, available at: http://dx.doi.org/10.14257/ijmue.2013.8.5.30

Raya, R., Rocon, E., Gallego, J.A., Ceres, R. and Pons, J.L. (2012), "A robust Kalman algorithm to facilitate the human-computer interaction for people with cerebral palsy using a new interface based on inertial sensors", *On Sensor*, Vol. 12 No. 3, pp. 3049-67.

Corresponding author

Jesus Victor Zegarra Flores can be contacted at: zegarraflores@unistra.fr