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ASSISTING PERSONAL POSITIONING IN INDOOR ENVIRONMENTS USING MAP MATCHING

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ABSTRACT: Personal positioning is facing a huge challenge to maintain a reliable accuracy through all applications. Although in outdoor applications, several mobile navigation devices can provide acceptable positioning accuracy, the situation in indoor environment is not the same. Mobile navigation devices mainly contain a global positioning system (GPS) receiver and an inertial measurement unit (IMU). The main drawback in indoor navigation applications is the unavailability of the GNSS signals, which decreases the possibility of obtaining an accurate absolute position solution, as the inertial system (INS) solution will drift with time in the absence of external updates. Several alternatives were presented lately to update the inertial solution such as using Wi-Fi, UWB, RFID, several self-contained sensors, imaging aiding and spatial information aiding. In order to achieve accurate position solution, with low-cost and usable technique, an integrated mobile navigation system integrating GPS/IMU/Wi-Fi and map-matching was developed. The developed system uses the prior knowledge of the indoor geometrical and topological information, as a threshold for the navigation solution, forcing the provided solution to be mostly on the right track. The geometrical and topological information for the building was used to build the geospatial data model. The use of this model was performed by developing a map matching algorithm which uses the geometrical and topological characteristics of the building to locate the user position on the building map. This algorithm was developed based on the geospatial information of the Engineering building, University of Calgary, where the field test occurred. The map-matching algorithm was evaluated by processing and comparing two separate navigation solutions through the study area, one using only the GPS/IMU/Wi-Fi system, and second solution was assisted with the map-matching algorithm which shows significant enhancement in the position solution for the indoor trajectory.

1. INTRODUCTION

Navigation systems play an important role in many vital disciplines. Determining the accurate location of a user relative to the physical environment (e.g. roadway, intersections, services) is an important part of a range of transportation services, for example in-vehicle navigation, fleet management and infrastructure maintenance (Syed, 2009). Also other services require locating a user to many physical indoor environment (e.g. airports, shopping mall, public buildings) to assist in many navigation applications such as E911, law-enforcement, handicapped movement and marketing services. Since all these applications require a trusted and reliable positioning, whenever the user is located in a GPS denied environment, there is a huge challenge to maintain this reliability. Several researches address possible methodologies to aid the current navigation systems in indoor environments with either additional sensors or special filtering, however reaching an absolute accurate and trusted position in these environment is a challenge till this moment (El-Sheimy, 2010). The emerging current technologies suitable for indoor navigation include ground-based RF systems, such as UWB and RFID; mainstream wireless communication systems, such as cellular phone and WLAN (e.g. Wi-Fi); vision aiding systems, such as cameras and lasers; and dead reckoning sensors, such as gyroscopes and accelerometers (Zhao, 2010). Considering the availabilities, accuracy and cost factors for mass production, the above candidate technologies face some limitations for practical implementations. Therefore it is a must to depend on multiple technologies as well as search for the optimal integration between these technologies, depending on the application, and assists them by other means if applicable (El-Sheimy, 2010).

Most of the navigation devices use a map matching technique to present the user's location on the map. Map matching itself has been developed to be more than just a visualization tool to locate the navigation data (position and direction) on a map. Mitigating the errors from navigation sensors and bridging the navigation solution have become one of the main tasks for any map matching algorithm (Attia, 2010). In indoor environment, where it is hard to provide a continuous reliable position estimate, map matching can bridge the navigation solution based on the floor alignments. The building information provide a logical threshold to bound the solution into a certain region, changing the main target of the navigation system from obtaining a high accuracy to position information to obtaining a position with enough accuracy allows the system to select the correct passageway.

This paper will address aiding indoor navigation systems with mapping information, getting benefit from the geospatial information for the navigated regions, i.e. floor plans. The navigation system uses a real-time hardware personal navigation system (PNS) developed at the University of Calgary. The PNS unit integrates GPS and microelectronics gyroscopes/accelerometers along with Wi-Fi Both performance and cost of this unit is comparable to the sensors used in smart cell phones (Zhao, 2010). Within the indoor environment, the GPS does not have any significant benefit through the navigation solution other than to initialize the position when the user enters the building. Personal Dead Reckoning (PDR) was used to integrate the sensors data with the Wi-Fi data. A map matching algorithm was developed to locate the position fix from the navigation solution on a developed geospatial data model for the navigated building. The algorithm uses geometrical and topological constraints to project the position on the nearest passageway taking into consideration the connectivity of the passageways. The main objective of this integrated algorithm is to provide a more reliable navigation solution working in indoor environment. A brief background on related work, the description of the system, testing environment and results will be discussed through the following sections.

2. MAP AIDING NAVIGATION SYSTEMS

Maps have been used for centuries to transit users from a certain place to another. For the last decades, navigation devices have used the digital form of maps to locate the position of the user on them in order to assist in providing the navigation directions. Recently maps have become more than just a visualization tool in navigation systems, but they have been an aiding tool in enhancing the reliability of the obtained navigation solutions. Navigation has a huge set of applications, which mostly use maps in their display, such as in-vehicle applications, personal navigation devices, and even smart phones with navigation applications. These applications usually use a navigation system consisting of a GPS receiver, a map and its geospatial database. Although, those systems usually provide accurate positioning information, it is limited to the open space environment. Navigation in GPS denied environments such as indoor facilities are facing a huge challenge to maintain the accurate positioning information due to the GPS signal blockage and multipath (Syed, 2009). Aiding these systems by integrating other navigation sensors such as INS is useful in some cases, but the drift in position errors with time due to GPS outages, still reduces the reliability of this solution in some applications.

The research of aiding navigation system using map matching deals with three aspects; selecting the integrated navigation sensors, designing the map matching algorithm and designing the geospatial model for the floor plans. For indoor applications and due to the signal blockage, GPS/INS integrated system requires another aiding source as discussed in the introduction section. For the second aspect, (Quddus, 2007) compare between several possible map matching algorithms according to their accuracy and concept. Generally, there are three types for map matching; geometrical and topological algorithms, probability algorithms and advanced algorithms such as using fuzzy logic, belief theory and Bayesian networks (White, 2000; Greenfeld. 2002; Quddus, 2003, Basnayake, 2005). The main difference between these categories is the method in selecting the matching link where the position will be projected on. The third aspect is choosing the appropriate map design which has the characteristics to support navigation application (Bullock, 1994). Maps for indoor application should model all possible passageways and height change access (stairs, elevators), and also consider the topological characteristics, for example connectivity between passageways. (Miesenberger, 2008; Arto, 2009) discuss the requirements for designing navigation based maps. (Gillieron, 2003, Khider, 2008; Glanzer, 2009) discuss some systems for indoor navigation with the assist of the building information. The main idea is to use the building information to create virtual boundaries for the navigation solution, which lead to bounding the solution in the most probable region, therefore increasing the reliability of the solution.

3. METHOD

As stated previously, the proposed algorithm based on three main components; the navigation system, the geospatial data model and the map matching algorithm. The integration between these three components is illustrated in figure 1. For the navigation system, the test system was set up consisting of a laptop with WLAN Mini-card, Garmin CS60X GPS and ADI ADIS1605 IMU. The IMU contains tri-axial digital gyroscope and accelerometer. All the sensors and GPS data are collected from USB port and the computer synchronizes all the data internally. The Wi-Fi positioning algorithm works on updating the navigation solution when GPS is not available, which is the case in most indoor environments. Wi-Fi positioning is based on the measurements of received signal strength (RSS) from the access point (AP), by using signal propagation model to convert signal strength to a distance measurement to the access point.

A loosely-coupled Extended Kalman Filter is applied to integrate tri-axial accelerometers and gyroscopes with Wi-Fi and GPS updates. The algorithm starts by using both accelerometer and gyroscope data which is integrated with GPS measurements once they become available. During good GPS/Wi-Fi updates, misalignment attitude angles between body frame and person frame are estimated (El-Sheimy, 2010). A Pedestrian Dead Reckoning (PDR) is adopted to minimize sensors integration errors and drifts by exploiting the kinematics of human gait with the traveled distance and heading information (Zhao, 2010). The algorithm contains step detection, stride length estimation and heading determination. Once mechanization derived heading is converged, the heading is used in PDR to compute Easting and Northing for the Kalman Filter; however if heading drifts too much, or if steps aren't detected with enough certainty, only mechanization is used. More details on the navigation system are discussed in (Zhao, 2010).

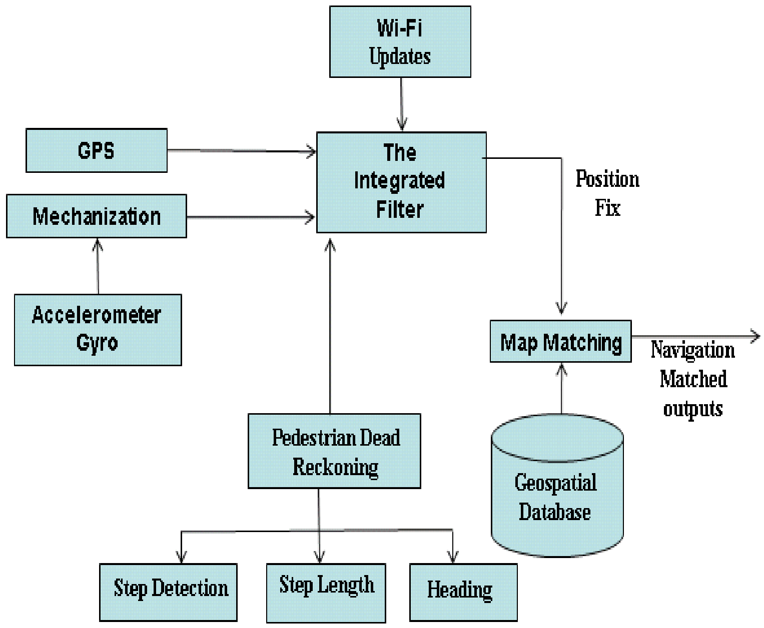

Fig. 1. Proposed map aiding algorithm

A geospatial data model was developed for the study area, which is the engineering building at University of Calgary. The floor maps, provided from the University geographical information library, was filtered to represent the regions surrounding the field test area. The geospatial model includes the geometrical modelling for the passageways, and the associated attributes. The passageways (corridors) were modelled as polylines (links) with two nodes; the start node and the destination node. All nodes were described by an identification number (ID) and a projected UTM coordinates. The associated attributes for the links include the floor number, proximity of a height change access, stairs, and all possible links diverged from its start and destination nodes. Figure 2 shows the geometrical layout for the model.

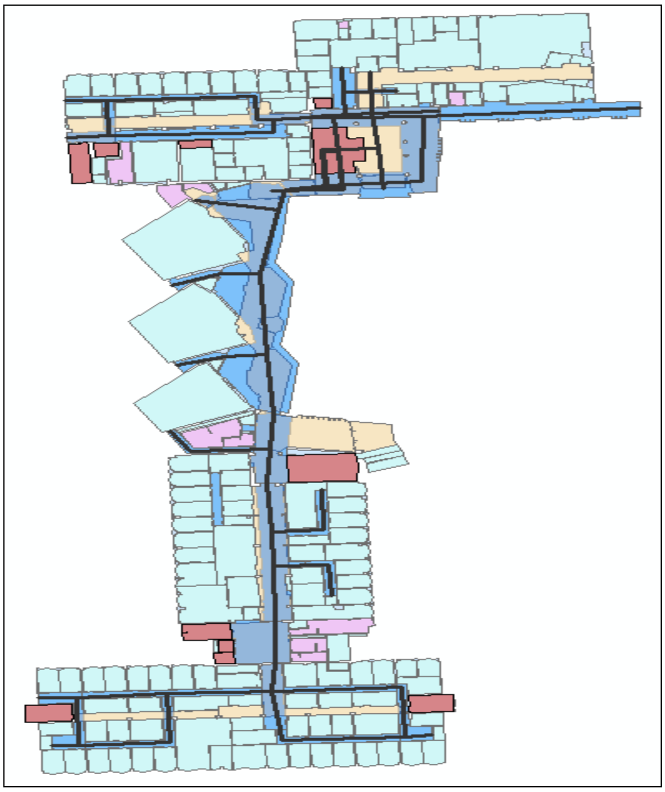

Fig. 2. Geospatial model for the study area

Finally, a map matching algorithm was designed to locate the position fix from the navigation system to the map. The map matching algorithm is based on the geometrical and topological algorithm developed in (Attia, 2010) with some modification to fit the indoor environment. Two different matching logics were developed. Both map matching algorithms are based on point to curve matching (Quddus, 2007). The point to curve map matching is based on projecting the position estimated from the navigation algorithm (X_S, Y_S) into the nearest link, which in this case is the nearest passageway. Each passageway link has a start and end nodes, [(X_1, Y_1), (X_2, Y_2)]. Using the position estimate coordinates (X_S, Y_S) a dot product between the position and the start and destination nodes [(X_1,Y_1), (X_2,Y_2)] is done as in equation (1) to calculate the minimum distance between the position estimate and all the links provided that the projection lies within the extent of the link. Equation (1) is based on the concept that the minimum distance between any point and a line is the perpendicular distance which is obtained using the dot product. After applying equation (1) on all the links, and once a link is selected, the algorithm will project the position estimate on the passageways links. The projected coordinates (X_P, Y_P) can be obtained using equations (2, 3) (Quddus, 2003).

Equations (2) and (3) simply calculate the coordinates in X and Y respectively for projection of the position estimate (X_S, Y_S) on the selected (nearest) passageway whose start and end nodes are [(X_1, Y_1), (X_2, Y_2)].

$$D = \frac{X_s(Y_1 - Y_2) - Y_s(X_1 - X_2) + (X_1Y_2 - X_2Y_1)}{\sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2}} \quad (1)$$

$$Xp = \frac{(X_2 - X_1)[X_s(X_2 - X_1) + Y_s(Y_2 - Y_1)] + (Y_2 - Y_1)(X_1Y_2 - X_2Y_1)}{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \quad (2)$$

$$Yp = \frac{(Y_2 - Y_1)[X_s(X_2 - X_1) + Y_s(Y_2 - Y_1)] - (X_2 - X_1)(X_1Y_2 - X_2Y_1)}{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \quad (3)$$

The difference between the two algorithms is how the navigation solution is projected. As for the first algorithm, it will read the first epoch position and project it on the nearest link using the previous technique. It will then keep reading epoch by epoch and project them on the nearest links. The second algorithm will start similarly to the previous one; however it will compute the shift between the first position estimate and the projected position. The algorithm will shift the whole navigation solution with this value before projecting the second epoch. Therefore for every epoch, the algorithm will first shift the solution with the previous epoch shift value, and then project its position on the nearest link. Figure 3 presents the outline and differences between the two algorithms. The results for both algorithms are illustrated in the next section.

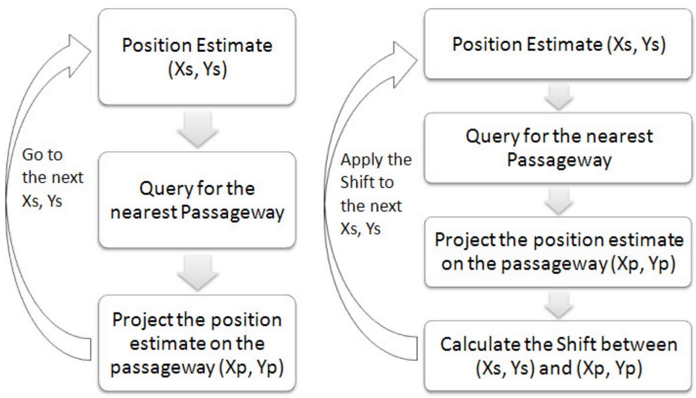

Fig. 3. The outline for first algorithm (on right) and the second algorithm (on left)

4. FIELD TEST AND RESULTS

Pedestrian field tests were performed in a number of indoor and outdoor scenarios to further verify the performances of this algorithm. The used dataset was collected in January 2010 at engineering building, University of Calgary campus. It is a ten minutes walk from outdoor to indoor, as shown in figure 3. The test started at the east door entrance of the building; the user then walked two loops outdoors and entered the building; then the user walked indoors and went upstairs to the second floor, after making several turns and walking along the hallways, the user finally stopped at the southwest side of the building (Zhao, 2010). In order to judge the useability of this data, the dataset was then evaluated using a reference trajectory, which was obtained from backward smoothing filters. By comparing it with this reference trajectory, the navigation solution got an accuracy of 10.5 m mean position error (3D) and 20.7 m maximum position error (3D).

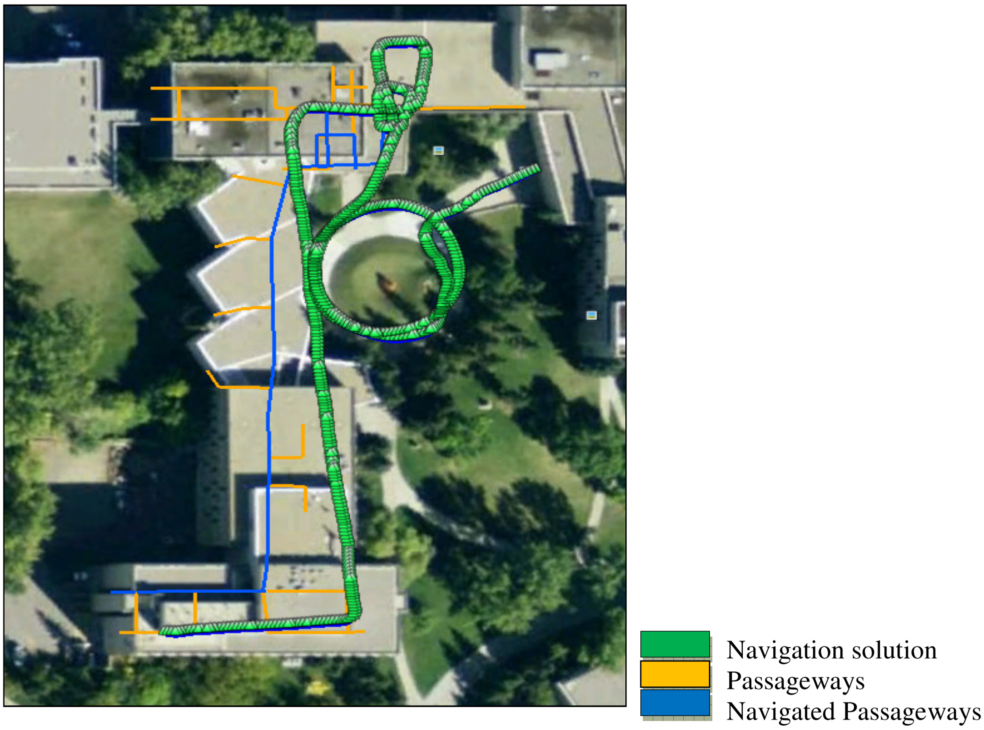

Fig. 4. Field test trajectory

Through most of the indoor trajectory the GPS was not available, which lead to the use of the Wi-Fi data. The receiver had an access to 250 access points along the trajectory, however only 12 APs (5 line of sight) were used due to their strong signal strength. Figure 3 shows the navigated trajectory (blue), all possible passageways (yellow) and the processed navigation solution (green). As discussed in the method section, the processed navigation solution was used epoch by epoch as the input for the proposed map matching algorithm.

Figures 5 and 6 show the map matching results for both algorithms respectively. The figure contains all the possible passageways (black), the processed navigation solution (blue) and the map matched path (red). As shown in the figure 5 and 6, it is clear that the second algorithm achieved enhanced matching results on most of the trajectory, however the second algorithm didn't get the same matching results for the stairs area as the first algorithm did (located on the upper right region of the trajectory). As illustrated in table 1, the first algorithm achieved a matching percentage of 69.96 % from the navigated passageways, and the second algorithm achieved a percentage of 72.02 %. This percentage measure the efficiency of the algorithm to detect the correct link and project the solution on this path. The percentage was simply calculated by comparing the number of the missed passageways with the total number of the navigated passage ways. It can be noticed that although the second algorithm has better results on most of the trajectory, but since it didn't achieve the same results on the stairs region (which count a long number of links) the overall percentage is not significantly higher than the first algorithm. These achieved results can simply illustrate the significance of the proposed algorithms in increasing the reliability of the navigation solution. This improvement could be noticed when assuming the map itself as our reference trajectory. The position error is reduced to a maximum 3D position error of 11.3 m and a mean 2D position error of 3.1 m.

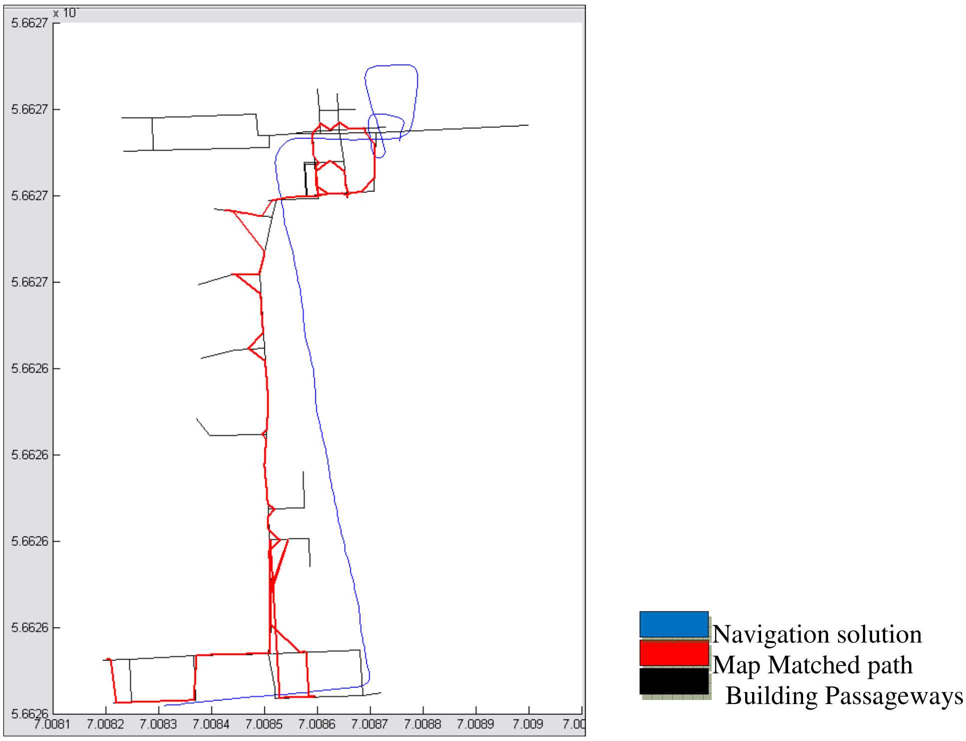

Fig. 5. Results for the first proposed algorithm

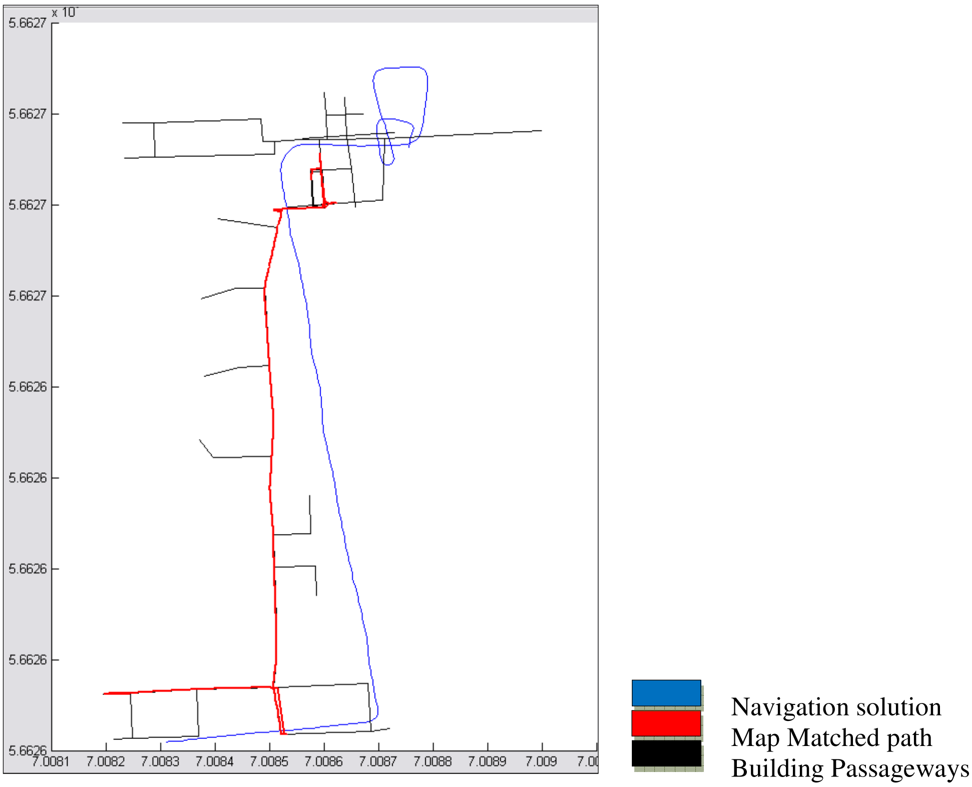

Fig. 6. Results for the second proposed algorithm

Tab.1. Matching Results for both algorithms

	Correct matched path
First algorithm	69.96 %
Second algorithm	72.02 %

5. CONCLUSIONS

In order to enhance the reliability of positioning solution inside indoor environments, this paper uses a map matching technique to assist a current pedestrian navigation system. The input for the algorithm is the navigation solution obtained from the GPS/INS/Wi-Fi integrated system. The algorithm uses the map matching to locate the solution on the most probable location (passageways), increasing the reliability of the overall navigation output. Two matching logics were field tested in the engineering building at University of Calgary, and the matching percentage was around the 70% for both. The achieved results of locating the navigated passageways can be very significant for many mobile mapping applications. Whether to be a standalone PNS, or built inside a smart cell-phone, this real-time, low-cost, usable, friendly system can be used in emergencies, law-enforcement, regular indoor navigation, handicapped, blind persons, and many other assisting navigation applications.

6. ACKNOWLEDGEMENTS

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