Pixel-based Map Matching Algorithm for Pedestrian Dead Reckoning System

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Abstract. City dwellers spend most of their time indoor. Therefore, indoor location-based services would have much more potential than outdoor. However, the width of a typical indoor pathway is 1.3 meter, making the indoor localization system accuracy a challenge. Moreover, the indoor clutters will scatter signal-based localization system accuracy unpredictable. Pedestrian dead reckoning system would be an ideal system. It uses motion sensing involves fusing data generated by inertial measuring units (IMUs) to compute the user trajectory relative to the initial position. It is an accurate and a simple system but the drift in the system make it unreliable for most practical use.

In this paper, we proposed a pixel-based map matching algorithm to minimize the drift error in a dead reckoning system. The practical results would be presented in this paper.

Keywords: Indoor Localization, Dead Reckoning System, Multi-sensor, Sensor Networking, Error Minimization, Internet of Things.

1   Introduction

Pedestrian dead reckoning (PDR) is the process of calculating one's current position the velocity provide by the system and previously known position. This relative positioning does not require any site survey or an intensive deployment of infrastructure, making PDR a very promising cost-effective technology for indoor localization. However, the relativity will allow error margin in the sensors' reading to accumulated over time, this error term as drift. The previously known position had an error, the current position calculated will include the error and this error will be magnify over time. The error accumulation over time is random. This make PDR unreliable for practical use.

Map-matching is the process of matching raw positioning data output from a positioning system to a map or two-dimensional (2D) navigation model depicting the surrounding physical environment [1-3]. It is first, and commonly used GPS navigation used outdoor and Geographic Information System (GIS) provide the standard format for the GPS navigation application [4-6]. However, no standard representation of indoor environments for indoor map-matching navigation is available [7]. Although indoor

architecture floor plan is available, the drawing is using associate with information not required for indoor map matching navigation.

In this paper, a map matching algorithm is proposed in minimizing the drift in a PDR. In leveraging on indoor floor plan, pre-determine path could be determined to minimize the drift in a PDR system.

2　Obtaining Map Information

This is a light weight manual method to obtain map information in assigning pixels to the corresponding coordinate (long, lat) for the use in indoor navigation with map matching algorithm. Although, there are automated map generation for navigation models from building information models [7]. The automated solution would require extensive for a single floor testing and is usually target whole building map generation.

2.1　Layering

The floor plan must be drawn to scale and converted into softcopy. The floor plan will go through layering to separate the essential information from non-essential information. The floor plan was layered into indoor/structural floor plan and the information layer. Only the indoor/structural floor plan is used in determining the pre-determine path.

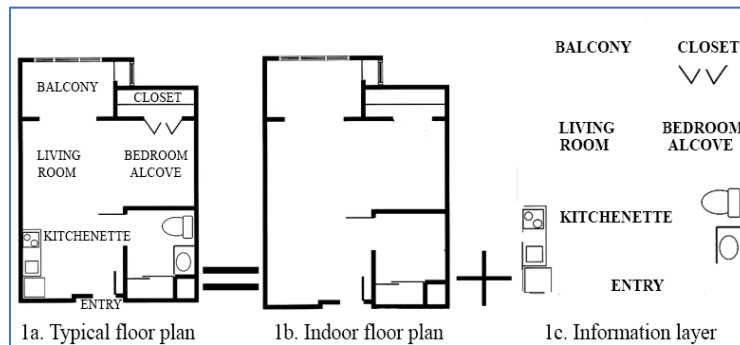An example of a typical floor plan layering is shown in Fig. 1.

Fig. 1. Layering out a typical floor plan

2.2　Pixelization

The digitalized indoor/structural floor plan will have each pixel presents a coordinate (latitude, longitude). The solid pixels or black pixels will represent walls or obstacles that will prevent the localization system to make its location on it or cross it. Thereby, creating allowable and non-allowable pixels for the localization system to navigate within these pixels. The continuity of the allowable pixels will be the pre-determine path containing the navigation of a PDR system. This will enhance accuracy and prevent localization system from navigate into the walls or over the walls.

2.3   Coordinate Assignment

The outline of the indoor floor plan is overlay onto the building outline in a Google map as shown in Fig. 2 Once outline of the indoor floor plan is aligned onto the Google map building outline.   The indoor floor plan circumference coordinate could be obtained, and each pixel's coordinate could be determined.   The resolution could be reduced to minimize the system resources.
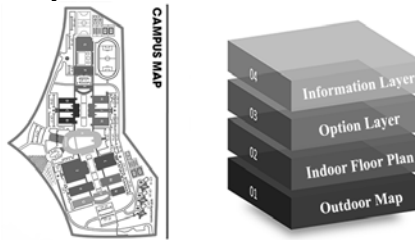

Fig. 2. Mapping the outline of the indoor floor plan onto Google Map to obtain the coordinates for each pixels in the indoor floor plan

3   Map Matching Algorithm

A pre-defined path will be defined to contain the PDR value within a certain range. The PDR reading will be moved to the pre-defined path pixels with k nearest algorithm.

Since the biggest problem from PDR is it is not calibratable when error accumulated along with the time, we have used map matching algorithm applied on every raw point from PDR and iteratively compared distance to the nearest path and nearest pixels. After calibrated to the nearest pixel in the predefined path, the accumulated error will be significantly limited to an acceptable range.

Fig. 3a shows the process flow.   At the beginning of the tracking, an initial tracking location together with the initial direction obtained from magnetometer is required for the system. The start point does not need to be accurate because the map matching system will assign it to the nearest pixel on the nearest path. There are two steps to determine the nearest pixel.   The graphical explanation is shown in Fig. 3b.   The initial direction of the moving direction as in Fig. 3b(i) is obtained from the magnetometer and subsequent direction is determined by the gyroscope.   The predefined paths directions with the initial direction determined by the magnetometer or the gyroscope will filter out all predefined path pixel located in the irrelevant direction as shown in Fig. 3b(ii).   To determine the nearest pixel along the remaining paths.   The existing location coordinates will compute the distances between its coordinates with the pixels coordinates along the pre-determine path as shown in Fig. 3b(iii). The existing location coordinates will be replaced with the nearest coordinates in the pre-defined path as shown in Fig. 3b(iv).   Iteratively, with movement sensed by IMU unit, previous assigned point together with step length and direction changed will be used to calculate the next predicted location and the final location will be assigned on the nearest pixel using the same strategy.
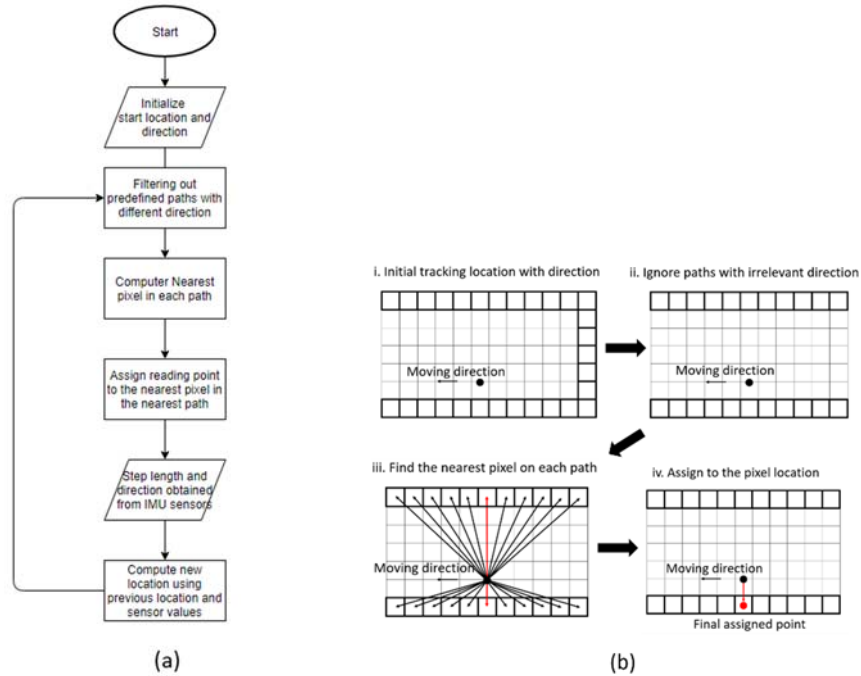
Fig. 3. (a) Map matching algorithm flowchart (b) Map matching algorithm example

Since, the algorithm will restrict the tracking within the pre-defined path, error will be significant at the turning of the cross junction where the PDR error accumulated could be overshoot or undershoot. This error will disallow the turning since the predicted location will be either after the cross junction or before the cross junction depending on the error is overshoot or undershoot. This drift error is random. In different situations it may mislead the next path decision in making turns.

Based on PDR practical result and typical steps sizes, in a straight-line pre-define path, the error accumulation does not exceed 4 meters. This indicate the system localization error with map matching is 4 meters and below or the misstep error is limited to slightly more 2 steps size. In factoring the system localization error in the system decision to determine if a turning is genuine. The allowable turn area is set to the current point to the nearest turn is ± 4 meters. The diagrams showing the errors undershoot (A) and overshoot (B) at the cross junction is shown in Fig. 4. If the predicted location is within ± 4 meters of the entrant point of the junction and a change of direction in the system, the previous direction will be disregarded, the calibrated position will be the entrant point of the nearest cross junction.

However, if a change of direction not within ± 4 meters of the entrant point of the junction, the previous direction will be considered as the factor. The next path of pedestrian will be the previous nearest facing path of the previous direction. This auto-calibrate the PDR direction error from the gyroscope or the magnetometer.
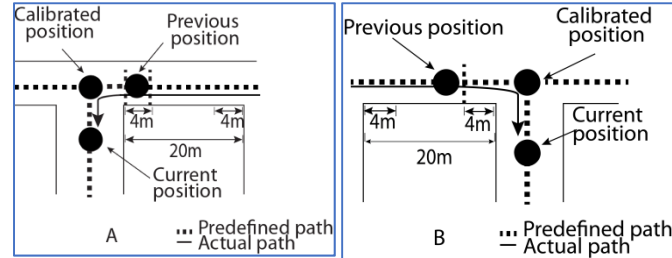
Fig. 4. Map matching algorithm for turning corners for undershoot situation (A), overshoot situation (B)

4 Experimental Results and Discussion

A PDR localization system based on accelerometer, gyroscope and magnetometer is developed on Android platform. The device used here is Samsung Note 4+. One device is with PDR localization system while another is using the same localization system with map matching algorithm mentioned in Section 3. The laboratory indoor map coordinates are extracted as discussed in Section 2.

An initial starting point is pre-defined and the coordinated is marked out together with a set of check points. The purpose of having the check points are mapped out is to the tester to record the reading at the same location for over 50 cycle of testing. This would provide consistency in having the test repeated for 50 cycles and reading taken in the exact same location. The test is carried with 34 pre-defined measurement points and test setup with two phones (same model). The test path is designed to have a reasonable number of turns and distance. One mobile phone will have a PDR with map matching algorithm while the other without on a notepad board to ensure both systems are subject to the same physical movement and conditions during each test cycle.

Fig. 5 show how the distance error is measured with the predicated position by system with reference to the pre-defined path. The distance error from the pre-defined path for system with map matching is termed as Δ. Δ_1 is the distance after the predicted point is move to the nearest neighbor on the pre-defined path. The distance error Δ_2 is measured directly from the predicted point by the system without map matching with respect to the pre-defined path.
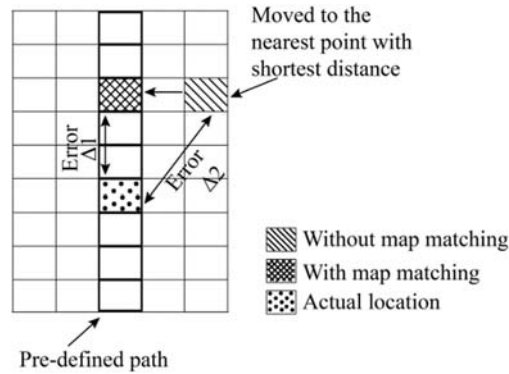
Fig. 5. Map matching algorithm in assigning the reading out value to the nearest neighbor in pre-defined path pixel with k nearest neighbor algorithm

The mean distance error at each check points for system with and without map matching algorithm for 50 cycles is shown in Fig. 6. The result shows the mean distance error at each check point for the system with map matching algorithm is constantly below the system without map matching. The average mean distance error is 2.07 meter and 6.13 meter for system with map matching and without map matching respectively. This suggest a drastic improvement in the distance error in using map matching algorithm.
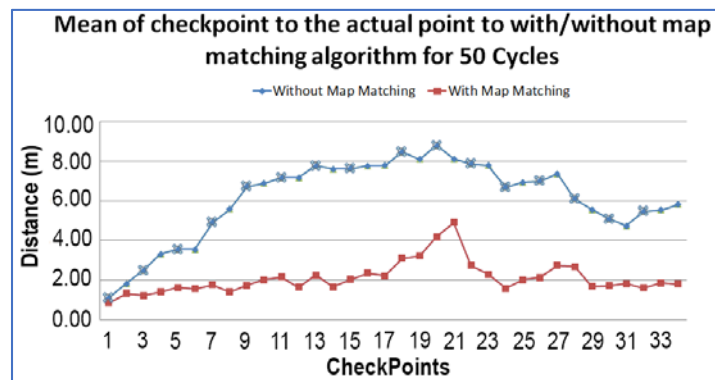

Fig. 6. Mean error value for each cycle

In Fig. 7 shows the variance and standard deviation at each checkpoint over 50 cycles. The variance and standard deviation are constantly lower in the system with map matching algorithm over the system without. This indicate the data produced by system with map matching is more consistent and closer to the mean value of the predicted value.

In Fig.8 show the improvement factors for each test cycle. The improvement factor per cycle, is calculated using the equation $\Gamma=(\Delta_2-\Delta_1)/\Delta 1$, where Γ is the improvement factor per sample. A linear trend line shows an approximate 55% improvement could be achieved using the map matching algorithm.
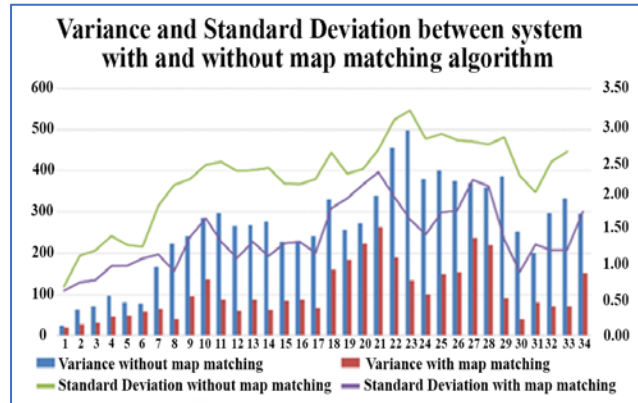
Fig. 7. Variance (y-axis on the left) and Standard Deviation (y-axis on the right) at each checkpoints (x-axis) over 50 cycles for system with and without map matching algorithm

Common techniques used in error correction in PDR uses estimating the step length and orientation change of each stride observing the characteristics of the IMU reading during steps [8,9] or if the IMU is located at the pedestrian's feet, an inertial navigation system (INS) [10] is used to correct the zero velocity UPdaTes (ZUPT) during the stance phases of step. Estimating the step length and orientation offers a flexible method but an increase in error after each step persist. INS offer better positioning at the cost of limiting the possible positions of the IMU (at the shoe).

However, our lightweight solution allows indoor map information transfer for our map matching algorithm to minimize error in the PDR navigation system. In confining the navigation space of each steps and allow every turn to perform system calibration to auto-correct the errors accumulated. The system drift could be contained within a finite time of each cornering.
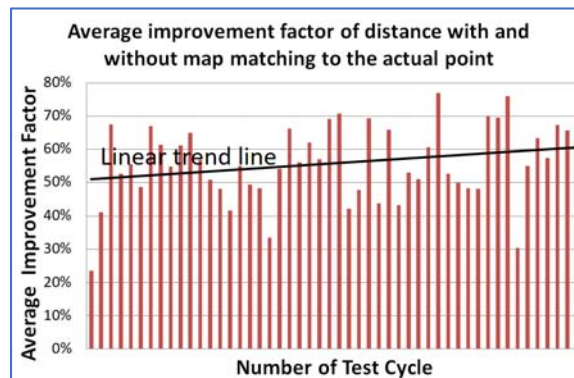

Fig. 8. Average improvement factor

The results had showed a drastic improvement in the system using map matching algorithm in term of accuracy and more consistently closer to the mean predicted value.

5   Conclusion

In this paper, we had proven a lightweight map matching algorithm through an experiment could drastically improve the system error. This map matching algorithm uses each cornering to auto-correct the drift. It also restricts the PDR predicted value from drifting away too far from the pre-define path or over across the wall, which is not possible logically. In pre-define the space of movement and calibrating at each cornering, the errors had reduced significantly to a mean system error of 2.07 meters. The value is also closer to the mean system error, smaller error deviation, which make it less noise. The average improvement factor over each had reduced by approximately by 55%. This map matching algorithm is not restricted for PDR use and could be extended to other indoor navigation platform to improve the accuracy.

Acknowledgement

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