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A HYBRID APPROACH TO GPS IMPROVEMENT IN URBAN CANYONS

Ashwani Kumar Aggarwal *

* Electrical and Instrumentation Engineering department, Sant Longowal Institute of Engineering and Technology, Longowal-148106, Punjab, India

ABSTRACT

GPS has become important tool in everyday life for safe and convenient transportation of automobiles. Pedestrians use hand held smart devices to know their own position in a town, modern vehicles in intelligent transport systems use relatively sophisticated GPS receivers for estimating current position of vehicle for safe driving. However, in urban areas with canyon of buildings where the GPS satellites are occluded by tall buildings, trees and reflections of GPS signals from nearby vehicles, GPS position estimation becomes poor. In this paper, a hybrid approach to improve GPS data is presented. GPS data is captured at a single point in urban area around which many tall buildings are present. The data is taken under different times of day so that satellites positions are changed and under dynamic environmental conditions so that occlusions are changed.. The data is processed and analyzed using statistical methods. The improvement methods are used to obtain an optimal position estimate among all the measured data points. The improvement results are compared with many publically available datasets. The obtained position estimation improvement made with the hybrid approach are promising.

KEYWORDS: Global positioning system, statistical approach, transport systems, least squares estimation.

INTRODUCTION

Global positioning system (GPS) is widely used in transportation and navigation systems. This paper addresses the problem of aligning 3D range images in world geodetic coordinate system under unstable GPS conditions in urban canyons. The need for such models arises from their usefulness in applications viz. in geological survey and in intelligent transport systems. To achieve the goal, the range data and hence improve on the computation time of alignment procedure.

We present a method for global alignment of 3D model under unstable GPS data which uses optimum set of GPS estimates to obtain transformation. Several evaluation methods confirm the accuracy of obtained global alignment.

The key contributions of our work are the following:

- A novel method for refinement of GPS data in urban environments.
- Reconstruction of 3D model of large urban structure in world coordinates.
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The rest of the paper is structured as follows:

Related Work has been discussed in next section. Proposed methodology, experimental setup, results and evaluation methods are given in subsequent sections. Last section concludes the work and discusses the potential future scope of the work.

RELATED WORK

The Reconstruction of 3D model from multiple range scans involves aligning the scans into common coordinate system. Boaz Ben Moshe et. al. [1] address the problem of erroneous GPS in urban canyons by introducing a post-processing refinement algorithm however authors make use of 3D map of environment for achieve such task. Mezentsev et. al. [2] use a low cost rate gyro along with GPS receiver as a solution to the problem but as mentioned earlier, sensor fusion has additional drawbacks.

A wide variety of methods have been proposed in the literature with classical work done by Besl. et. al. [3]. The authors address the problem of alignment based on iterative closest point algorithm which always converges monotonically to the nearest local minimum. However, the problem with the method is decrease in rate of convergence after little iteration and hence the alignment achieved with the procedure is not time efficient.

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In [4], Zhang improves upon the time constraint of ICP with a heuristic approach which makes use of a priori information, for example, the motion between successive positions is usually approximately known. However, the method cannot be used in general in situations which lack such a priori knowledge.

Our aim is to reconstruct a 3D model in world geodetic system and not just in an arbitrary global system. We have such an objective from the geological survey applications where each point of reconstructed 3D model must have its coordinates in world coordinate system. To achieve our goal, we use sensor fusion of laser range sensor with GPS sensor.

Multi sensor fusion has been attempted in the past by many researchers to obtain global alignment. One of such work done by Hossein Madjidi et. al. [5] investigate the problem of global alignment of 3D points knowing the relative position between pair wise nearby positions. Their mixed adjustment model paradigm for recursive estimation relies on explicit model functions which are not always known.

Another recent work in this domain is by Abraham Bachrach et. al. [6] in which authors present a solution for navigation in GPS-denied environments but their system leverages a multi-level sensing and control hierarchy which is not only infrastructure wise inefficient but also limits their applicability in custom environments only.

RESULTS AND DISCUSSION

To achieve the goal of global alignment, we mount a GPS antenna on to a laser range scanner and take this assembly to the target environment which in our case is a huge building in urban environment. The GPS signal around the building is very unstable in the sense that GPS signal is either not available at many positions or if available has very poor signal. Several range images are taken around the building with a distance of around 3-5 meters between consecutive scans. At each of the scanned position, several shots of GPS data are logged in by GPS receiver. The range images are simultaneously aligned in a common coordinate system using ICP algorithm. GPS data at selected positions with high probability of position estimation accuracy is used to estimate the transformation between GPS position estimates and scan center positions obtained from simultaneous alignment of range images.

Outliers are rejected by confidence of GPS data and sufficient number of GPS positions is selected among all the positions using threshold based on number of visible satellites and their geometric orientation, both of which are given by GPS receiver. As all the selected positions do not have same position estimation accuracy, different weights are assigned to these positions during least square estimation of transformation.

The weights are assigned depending on the occlusion states at these positions. The occlusion states can be measured from the range image data obtained from laser range scanner. To further improve the GPS refinement, optimization is used which iteratively removes a random position from set of selected GPS positions to check its effect on the alignment. The obtained transformation is used to transform all the aligned 3D points into world coordinates.

To evaluate the correctness of constructed model, various evaluation methods based on orientation of building facades, positioning on aerial photos and overlapping of neighboring regions are considered. The last two evaluation methods have been discussed in the present paper. The evaluation results confirm the correctness of the global alignment.

GPS Refinement

We have used two different approaches to refine the GPS data. One is based on applying thresholds based on statistical inferences drawn on number of satellites visible and their geometric orientation while the other is based on optimization technique.

GPS Refinement based on Thresholds

GPS Refinement based on ThresholdsSeveral GPS readings are logged at fixed position with 10 Hz frequency. From the collected GPS data, population of different number of satellites visible is analyzed and then threshold is applied based on minimum number of satellites visible. More is number of satellites visible at a position, better is the position estimate. However, position estimation accuracy not only depends on the number of visible satellites but also on their geometric orientation. If the satellites are not geometrically spread enough, the estimation is poor. Therefore, second threshold was chosen based on their geometric orientation which is given by horizontal dilution of precision (HDOP) value. To compute HDOP, matrix A is formulated as follows.

$$A = \begin{bmatrix} \frac{(x_1 - x)}{R_1} & \frac{(y_1 - y)}{R_1} & \frac{(z_1 - z)}{R_1} & -1 \\ \frac{(x_2 - x)}{R_2} & \frac{(y_2 - y)}{R_2} & \frac{(z_2 - z)}{R_2} & -1 \\ \frac{(x_3 - x)}{R_3} & \frac{(y_3 - y)}{R_3} & \frac{(z_3 - z)}{R_3} & -1 \\ \frac{(x_4 - x)}{R_4} & \frac{(y_4 - y)}{R_4} & \frac{(z_4 - z)}{R_4} & -1 \end{bmatrix} \quad (1)$$

where x, y, z and x_i, y_i, z_i denote the position of receiver and that of satellite respectively and R_i denotes the distance of receiver from satellite.

The DOP factors are functions of diagonal elements of the covariance matrix as given below:

$$Q = \left(A^T A\right)^{-1} = \begin{bmatrix} d_x^2 & d_{xy}^2 & d_{xz}^2 & d_{xt}^2 \\ d_{xy}^2 & d_y^2 & d_{yz}^2 & d_{yt}^2 \\ d_{xz}^2 & d_{yz}^2 & d_z^2 & d_{zt}^2 \\ d_{xt}^2 & d_{yt}^2 & d_{zt}^2 & d_t^2 \end{bmatrix} \quad (2)$$

The horizontal precision of dilution is as follows.

$$HDOP = \sqrt{d_x^2 + d_y^2} \quad (3)$$

Conversion of GPS data into Geodetic System

Local geodetic datums have been adopted by many countries so as to use them in land surveying applications. Latitude and Longitude values obtained from GPS receiver are converted into X, Y positions in local geodetic datum.

Transformation Estimation

We The problem of transformation estimation between two coordinate systems given a set of corresponding points is studied in computer vision community from the past. A survey of many methods to estimate 3D transformation between two point sets is done by Sabata and Aggarwal [7]. Methods differ in a way whether correct correspondence between points in two sets is known or not. In our case, we know the exact correspondence between points in two datasets. One set of points is global positions obtained from GPS sensor and another set of points is positions obtained from local alignment.

Let P and Q be the 3D positions obtained from GPS sensor and locally aligned scan centers obtained from simultaneous alignment of range data respectively.

Given $P[x' \ \ y' \ \ z']^T$ and $Q[x \ \ y \ \ z]^T$ as two sets of corresponding points, we are interested to estimate the transformation matrix with 6 DOF which encapsulates rotation and translation around x, y, z axes.

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \alpha \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} \quad (4)$$

The minimum number of 3D points required to obtain a transformation between two sets of points is 3 in each set. We use least squares method to obtain the transformation between two point sets so as to minimize the sum of squares of distance between points in first set and transformed points in the second set.

$$e^2(R,T) = \frac{1}{n}\sum_{i=1}^{n} w_i \left\| y_i - (Rx_i + T) \right\|^2 \quad (5)$$

As all the positions are not equally good for estimating the transformation, we use variable weights in the least squares estimation. The weights are assigned depending on the occlusion state at each position which is known from the 3D points in the laser scan.

EXPERIMENTS

To achieve the goal of global alignment under unstable GPS conditions, we conducted the following experiment.
A GPS antenna was placed on the top of laser range scanner and the assembly was moved around a huge building in urban environment to capture GPS data at various positions and to obtain range data at those positions. A total of 149 scans were taken from ground around the target building with a distance of 3-5 meter between consecutive scans. In addition, a total of 35 scans were taken from rooftop of a neighboring building for evaluation purpose.
Trimble 5700 GPS receiver was used in our experiments which is capable of communication with external system as per NMEA standard. A logging rate of 10Hz and baud rate of 38,400 bps was selected to capture GPS messages from the GPS receiver.
Leica C10 Scan Station scanner was used for obtaining range data. The scanner is of time-of-flight type with an operating range of 1-200 meter and with scan rate of up to 50,000 points/sec. The horizontal and vertical field of view of the scanner is 360° and 270° respectively.

RESULTS AND DISCUSSION

As seen in Figure 1, the GPS positions obtained from ground around the huge building (target dataset) suffer from poor position estimates at many positions.

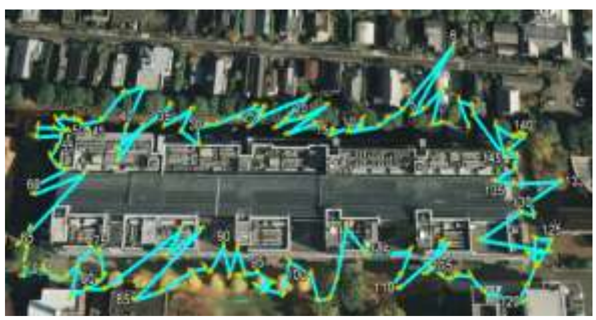

Figure 1*: GPS positions overlaid on aerial photographs (for the target dataset)*

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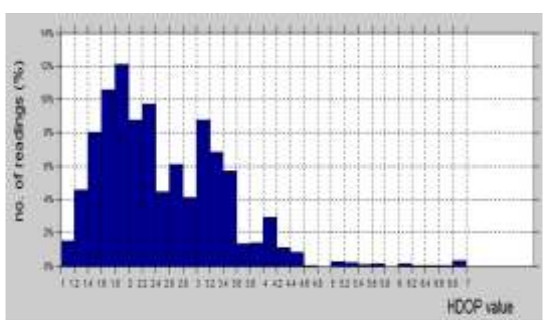

Figure 2*: Histogram of HDOP values for Geometric configuration of satellites*

This is mainly due to occlusion of satellites from the surrounding buildings. Moreover, even though number of satellites visible at a position is sufficient, their high value for dilution of precision deteriorates the accuracy of position estimates. A distribution plot of their dilution of precision values is shown in Figure 2. An optimum set of GPS positions were selected after applying thresholds based on number of satellites visible at that position and their geometric orientation.

Modeling of database

To evaluate the accuracy of global alignment for the target dataset, a reference dataset having an overlap with the target dataset was scanned from the rooftop and then aligned independently into world coordinates. The GPS positions measured from the rooftop of reference dataset are noticeably much accurate than those obtained on ground for the target dataset.

Overlapping of neighboring structures

The reference dataset was aligned and transformed into world coordinates independently from the target dataset using GPS positions taken on the rooftop. As the GPS position estimations are quite accurate on the rooftop, therefore the 3D model of the reference dataset is transformed into world coordinates with reasonable accuracy. The overlap of target dataset with the reference dataset both placed in world coordinates independently.

A plot of decreasing sum of distance square of corresponding points in the overlap region with number of iterations in optimization technique is shown in Figure 3. The overlapping distance decreases with each iteration which ensures the improvement on the global alignment of range data. It shows that adopting optimization method improves the alignment accuracy significantly.

Figure 4 shows scan positions of target dataset obtained after transformation into world coordinates. This confirms the correctness of the global alignment of target dataset into world coordinates.

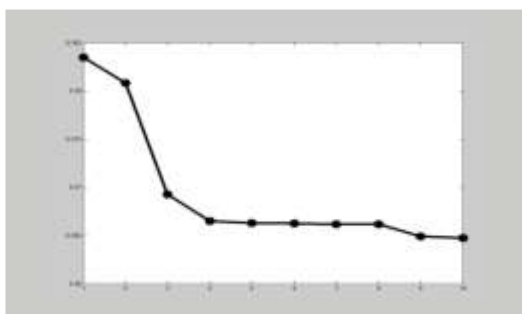

Figure 3*: Improvement with Optimization technique*

Figure 4*: Scan Positions of target dataset after transformation*

CONCLUSION

In this paper, we have proposed a method to align 3D model into world geodetic system under unstable GPS condition. We refined the GPS data based on statistical inferences drawn on number of visible satellites and their geometric configuration and used optimization technique to further improve upon the refinement result. The

obtained global 3D model has been evaluated with many evaluation methods. For the future work, we propose two different directions in which the current work can be extended. One is, a standalone approach would be implemented without dependence on the neighboring environment to remove the inaccurate GPS positions.
Another direction to which the current work can be extended is to update 3D model where significant changes have occurred in the environment e.g. new structure built or old one removed. In that case, a naive solution is to take the laser range scanner and the GPS sensor to capture the data again and repeat the procedure to obtain new 3D model. However, as taking data with laser range scanner along with GPS sensor in large environment and repeating the procedure of alignment is not only time consuming but is also inefficient. The result of this research can be used for an efficient solution to update the 3D model with minimal cost. First, the renovated region in the environment can be detected quickly and with less effort by 3D matching and then only renovated region could be scanned instead of scanning whole environment under consideration. This would make the solution more efficient.

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AUTHOR BIBLIOGRAPHY

Ashwani Kumar Aggarwal
Ashwani Kumar Aggarwal did his Bachelor of Engineering in Electronics and Instrumentation Engineering in 1996, masters degree in 2002 and PhD degree in 2014. He is working as Assistant Professor at Sant Longowal Institute of Engineering and Technology, Longowal, Punjab, India.