

Map-Based Positioning Method for Vehicle Trajectory Control

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ABSTRACT

Aimed to provide an effective solution for control-oriented applications, this paper proposes a novel method using a high-precision digital map to achieve high-accuracy positioning with fast updating rate. First, the map is developed using a high-definition LiDAR (Velodyne HDL 64E) and a RTK-GNSS system, which contains lane-level waypoints, road width, curb and typical obstacles along the road. Next, a robust version of ICP (Iterative Closest Point) is proposed to clean the corresponding points of large errors on map matching (MM). Finally, based on the large set of data from the environmental map, an unscented Kalman filter (UKF) is applied to fuse GNSS signal and dead reckoning (DR) to estimate the position. Thus the searching scope on the map can be considerably reduced so that the matching speed can be greatly improved. The high-precision digital map can be used not only for global path planning, but also for local driving detection and path planning. Experimental results demonstrate that even under urban environment with possible occlusion by buildings and trees, the positioning accuracy can still reach within 10cm with update rate to be up to 20Hz.

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INTRODUCTION

From state-of-the-art technologies of intelligent vehicles, positioning has not been paid adequate attention. However, this has been changed more recently as evidenced by DARPA Urban Challenge, where vehicles track its desired trajectory safely and accurately with positioning at decimeter-level accuracy and no less than 10Hz update rate [1]. Although satellite-based positioning method is still the most popular and mature way, the problems in using GNSS (Global Navigation Satellite System) are that its signal can often be obstructed by surrounding objects, and its update rate is too low to be sufficient. Mounting research has been conducted aimed to improve the performance of GNSS, such as RTK, inertial navigation system (INS), DR, visual odometry, etc. The problems remain to be solved, in particular, under "urban canyon" for sufficient long period. Other technologies that utilize radio frequency identification (RFID), ultra wide band (UWB) and 5G are mainly based on wireless communication, which is hardly feasible for practical applications in a large scale.

The integration of GPS and DR or INS has been extensively studied for years [2][3][4][5][6]. These systems use GNSS signals to adaptively calibrate the sensors as well as to "rescue" the system from unexpected position errors. Setting aside the price factor, the integrated navigation system, as complementation of satellite navigation system, is still incompetent for urban complex environment for long period. The LiDAR or camera is then added to solve the positioning failure in "urban canyon" [7][8][9][10]. The stereovision based visual odometry or feature based navigation technology was used to estimate vehicle pose and then fused with other integrated navigation systems. The wireless communication based positioning technologies such as RFID [11][12][13] and 5G [14][15], together with connected vehicles, have also been proposed in solving the issues under some particular scenarios.

However, some sensors like camera have their limitations in the computational speed and robustness of the signal processing algorithms that greatly restrict their applications. Wireless communication technologies, on the other hand, are highly dependent

on road infrastructure, and thus are mainly used in small-scale or indoor environment. The flexibility and initial cost have been the major issues.

As positioning problem is usually transformed to distance measurement problem, this paper uses 3D LiDAR to make lane-level digital map, whose measuring precision reaches 2cm. The digital map is a hybrid topological-grid map, in which the topological part is built by RTK-GNSS, and has acquired millimeter scale accuracy. It is mainly used for global path planning. And the grid map is used for local path planning and vehicle positioning by map matching. A robust version of ICP algorithm is introduced to do MM, which can effectively clean the corresponding points of large errors and improve the matching precision. In order to reduce the computational tasks and further improve the reliability of algorithm, the GNSS/DR integrated navigation system was introduced to pre-estimate vehicle pose, thus limiting the LiDAR's searching scope in 5m. The technology roadmap is shown below:

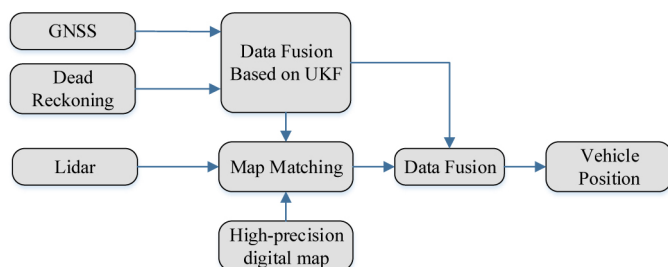


Figure 1. Technology roadmap of map-based positioning method.

This paper is organized as follows: Section II discusses the characteristics of GNSS and augmentation systems. Section III describes the process of producing the high-precision digital map in detail. Section IV introduces the GNSS/DR integrated navigation system which is based on UKF algorithm. The map matching is introduced in Section V, and the final positioning results is analyzed. Section VI concludes the paper with a brief summary.

GNSS AND AUGMENTATION SYSTEMS

There are three GNSSs that is currently widely used: 1) the American GPS; 2) the Chinese BDS; 3) the Russian GLONASS. Further, the European Galileo is coming into service. This paper doesn't aim to compare the differences between three navigation systems but to talk about the deficiency when they are applied for vehicle trajectory:

1. The accuracy of these system remains 5~20m. A main problem of TOF (Time of Flight) based positioning method is time synchronization. It's difficult to measure the delay between satellites and receiver clock. Moreover, the surrounding objects including trees and buildings may partly block satellite signals, forcing the GNSS receiver to work with a poor geometric constellation of satellites, thereby reducing the accuracy of the position estimates.
2. The continuity of the navigation solution may be interrupted when less than four satellites become available; Therefore, the navigation system is useless for in-door environment.
3. The update frequency is 1Hz, which is widely available for civilian uses.

Due to the limitation of accuracy, continuity and update frequency of GNSS, some augmentation systems such as DGPS and RTK have been developed to remedy its weaknesses and deficiencies. And Due to the low-cost and high accuracy of short term Nevertheless, it's still scarcely possible to solve positioning problem in urban environment. As a complementarity, DR is widely used for in-car positioning and navigation technologies for its low cost and high accuracy of short-term. Although INS can provide a higher-accuracy and more durable localization and even estimate the vehicle states parameters, the corresponding costs increase sharply.

HIGH-PRECISION DIGITAL MAP

Self-driving cars require an incredible amount of information to operate safely. As the environment on which vehicle drives is not totally unknown, some information such as the location of trees along the road, streetlamps and telegraph poles, don't need to be real-time perceived, but can be told in advance from a digital map, thus provide an easy way to for vehicle trajectory planning, decision and control to acquire the detailed surrounding information Traditional navigation map is of road level which only scratches the outline of the road. Figure 2 shows the differences between traditional navigation map and high-precision map [16].



Figure 2. Traditional navigation map (on the left) consists just roads themselves, while high-precision map (on the right) draw out every lane.

The high-precision digital map is made by using Velodyne HDL-64E and RTK-GNSS product, which is called M300 and produced by ComNav Technology Ltd. Figure 3 shows the map data acquisition equipment in Touran Test Platform.



Figure 3. Velodyne HDL-64E and RTK-GNSS product in Touran Test Platform

The single point positioning accuracy of M300 remains at millimeter level which is verified by test. Figure 4 shows the test scene in bird's view, the green line is the vehicle trajectory, and there are four test points along the road. While vehicle passed through the test points, it stopped and measured the positioning results for a certain time, then drove to the next. The test has been done twice.



Figure 4. Test scene in bird's eye view

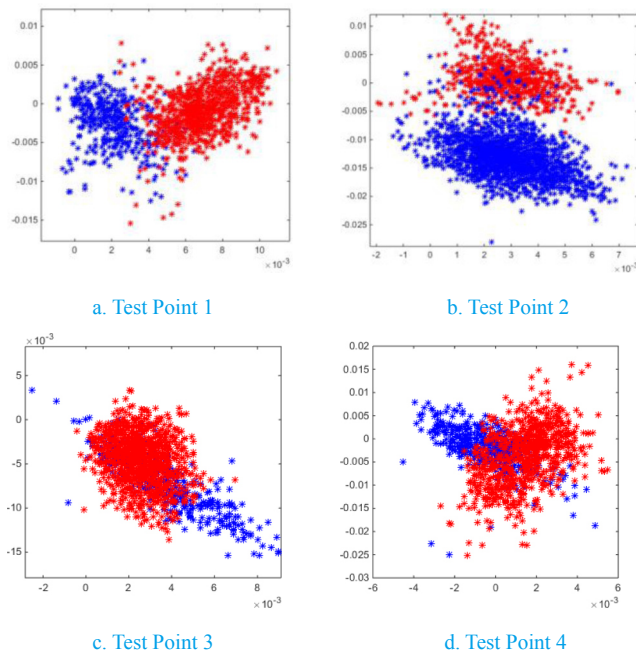


Figure 5. Scatter diagram of longitude-latitude, which has been transformed to x-y in rectangular coordinate system

Figure 5 shows the twice positioning results of four test points. The raw longitude and latitude data has been transformed to x-y value in rectangular coordinate system according to the WGS-84 reference ellipsoid. The coordinate unit is in meters. The results indicate that the positioning error of M300 doesn't grow over time or increase with travelled distance. What's more, the accuracy keeps in millimeter level throughout the test.

Figure 6 and Figure 7 show part of the digital map, which includes topological and grid map. The topological map contains the precise locations of waypoints, streetlamps, trees, road curb and speed humps. Road width and lanes information are also available. Actually, any static object you want can be measured to put into map so as to make intelligent vehicle get a better understanding of driving environment. The grid map has been pre-processed to remove the useless information including road surface and insignificant

obstacles. Grid map is used for map matching and topological map provides the precise location, they are interrelated and complementary.

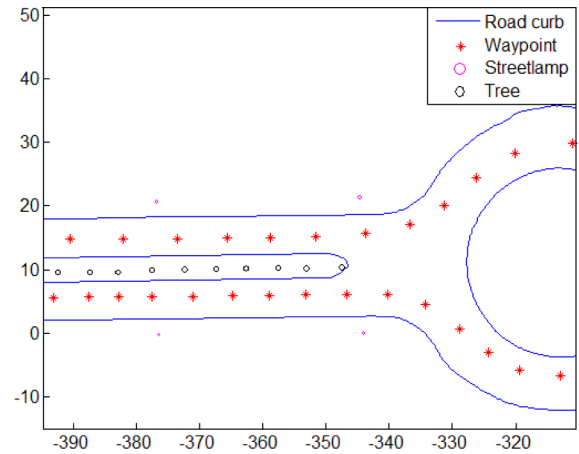


Figure 6. Topological Map

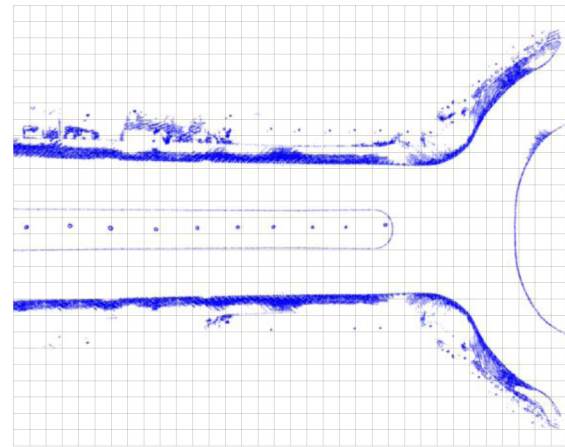


Figure 7. Grid Map

DEAD RECKONING

If approximate location of vehicle is known, then to fix the precise coordinates will be much easier. And as discussed in Section II, aside from the accuracy, it's still quite necessary to add augmentation system because of the advantages of continuity and update frequency. Dead reckoning is used in this paper to fuse GNSSs data and vehicle motion information. As the nonlinear features of vehicle kinematic model, traditional fusion method such as Kalman filter (KF) is not applicable. An unscented Kalman filter (UKF) is proposed to fuse the positioning information as it uses sampling method to describe the probability density distribution of the nonlinear control system approximately, thus without linearizing it.

Vehicle Kinematic Model

The vehicle motion information we used including steering wheel angle and velocity are all from in-car sensors, which can be read from CAN bus of vehicle chassis. And the vehicle kinematic model is shown in Figure 8. $X_w O_w Y_w$ is the world coordinate system (x, y, n) indicates vehicle's pose in which the location coordinate is (x, y) and