

Map-Based Localization Method for Autonomous Vehicles Using 3D-LIDAR^{*}

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Abstract: Precise and robust localization is a significant task for autonomous vehicles in complex scenarios. The accurate position of autonomous vehicles is necessary for decision making and path planning. In this paper, a novel method is proposed to precisely locate the autonomous vehicle using a 3D-LIDAR sensor. First, a curb detection algorithm is performed. Next, a beam model is utilized to extract the contour of the multi-frame curbs. Then, the iterative closest point algorithm and two Kalman filters are employed to estimate the position of autonomous vehicles based on the high-precision map. Finally, experimental results demonstrate the accuracy and robustness of the proposed method.

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Keywords: Autonomous vehicle, vehicle localization, 3D-LIDAR, curb detection, map matching

1. INTRODUCTION

Autonomous driving technology is rapidly growing to meet the needs of road safety and the efficiency of transportation. Autonomous vehicles can be used for many applications where driving may be inconvenient or dangerous. In order to improve the intelligence of autonomous vehicles, the information of precise vehicle position is required. Knaup and Homeier (2010) summarized that differential global positioning systems (GPS) and Inertial Measurement Units (IMU) were usually applied for localization system in the past few decades. The required accuracy can not be guaranteed due to insufficient number of visible satellites or multi-path reflections of the signal.

Researchers have proposed many map-based vehicle localization algorithms due to the availability of accurate digital navigation maps. Gruyer et al. (2014) used two lateral cameras to detect the road markings and estimated the lateral and directional deviations by coupling the cameras with the map data in an extended Kalman filter (EKF) framework. The accurate longitudinal position of autonomous vehicle is also required in real driving scenarios. Schreiber et al. (2013) applied a stereo camera system to recognize the environmental features of lane markers and curbs. Then, the iterative closest point (ICP) algorithm was used to match the pre-built accurate map data with the detected features. The error of lateral and longitudinal position of autonomous vehicle was corrected. However, the position of the lane markers was detected and calculated under the assumptions of fixed vehicle posture and flat ground. The intrinsic and extrinsic parameter sensitivity of camera was analyzed by Tao et al. (2013) and only the lateral position of lane markers was used to locate the vehicle. It is extremely difficult for cameras to

accurately extract the road features in shadow or poor lighting environment.

The LIDAR sensor is insensitive to illumination and the returned point-cloud contains the 3D environmental information. An IBEO laser scanner was used for vehicle localization by Schlichting and Brenner (2014). The 3D features such as pole-like objects and planes were measured and matched to the landmark map using a local pattern matching algorithm. It is hard to ensure the high correct-matching rate because of the sparsity of poles and planes. The lane markers can also be detected by LIDAR sensors based on the different reflectivity between the lane marker and the surface of road. A lane map-based localization algorithm using LIDAR sensors was proposed by Kim et al. (2015); Matthaei et al. (2014). The curbs detected by LIDAR have been used for localization Hata et al. (2014). The localization algorithm is performed under the assumption of flat road surface which is hard to guarantee in most scenarios. Due to the complexity of environment, the feature detection algorithms perform poorly and the outliers of feature usually exist in real-driving scenarios. A probabilistic grid map was utilized by Levinson and Thrun (2010); Wolcott and Eustice (2014) for localization in order to skip the feature detection procedure. The online sensor-data were directly matched with the map by traversing the lateral and longitudinal search space. Nevertheless, the computational complexity of the algorithm is high because all the sensor data are used for matching the map.

In this paper, a Velodyne 3D-LIDAR sensor is used and multi-frame features are generated to represent the complete both-side curbs. The curb detection algorithm is robust and does not require the assumption of flat road surface. In order to reduce the influence of outliers and achieve higher accuracy of localization, several beam models are launched to eliminate the most of outliers. The remained paper is organized as follows: Section 2 proposed the localization algorithm based on the high-precision

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map. Section 3 presents the simulation results and real-time experiments. Section 4 makes a conclusion of this paper.

2. CURB-MAP BASED LOCALIZATION

This section introduces the curb-map based localization algorithm. First, an algorithm of curb detection is performed on the point cloud of single-frame. Based on the vehicle dynamics, the detected curbs are densified by projecting former curbs into the current vehicle coordinate system. Then, the beam model is applied to extract the contour of the densified curbs. Finally, the extracted contour is matched to the high-precision map by ICP algorithm. The framework of the proposed algorithm is shown in Fig. 1.

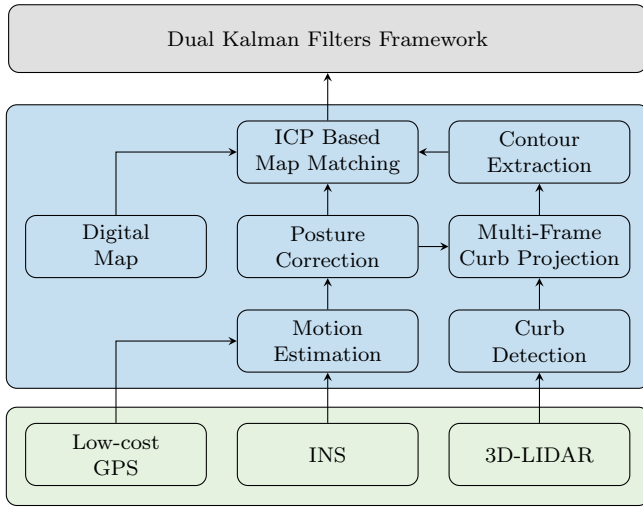


Fig. 1. Framework of the proposed algorithm

2.1 Curb Detection

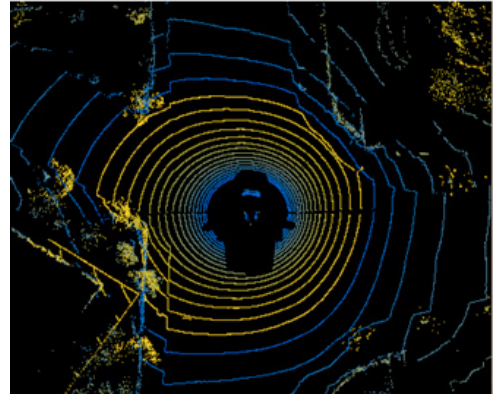
The Velodyne HDL-32E LIDAR is small, lightweight, ruggedly built and contains 32 lasers. It provides a 360° horizontal field of view and a 41.3° vertical view. The measurement range is up to 70 m with a resolution of 2 cm.

In this paper, the LIDAR sensor is mounted on top of an autonomous vehicle shown in Fig. 2(a). The raw data is obtained in a 3D polar coordinate as shown in Fig. 2(b). The curbs are detected from their spatial features. The height of curbs is uniform in most urban areas and it is often 10 to 15 cm higher than the road surface. Furthermore, the elevation changes sharply in the vertical direction. Based on these features, a robust approach was proposed by Zhang et al. (2015) to recognize curbs from a single frame. The detection result is shown in Fig. 3.

The density of the detected curbs decreases with the increase of distance. In order to obtain a complete representation of the curbs, multi-frame curbs are transformed into current vehicle coordinate system based on the dynamics of the vehicle. The sensor coordinate system changes along with the autonomous vehicle. Wheel speed sensors and an Inertial Navigation System (INS) are utilized to measure



(a) Autonomous vehicle



(b) 3D point cloud

Fig. 2. Experimental platform

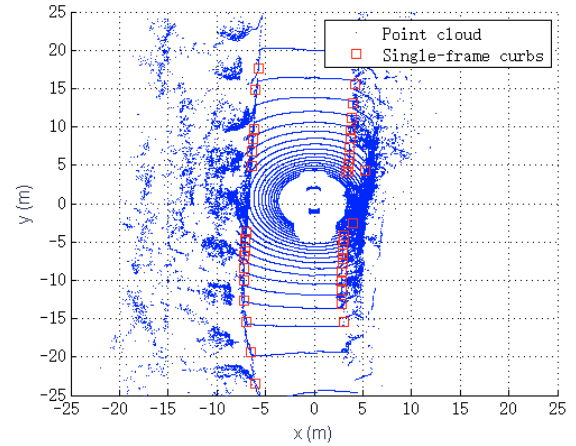


Fig. 3. Single-frame curbs

the motion of the vehicle. The position and heading deviations between two frames are defined as d_x , d_y and d_θ on the x - y plane. The detected curbs of single-frame are denoted by \mathbf{Q}_k , where $\mathbf{Q}_k = [\mathbf{x}_k \ \mathbf{y}_k]^T$ is the k th frame curb coordinates. Thus, the multi-frame curbs are denoted by:

$$\mathbf{R} = [\mathbf{Q}_k \ f(\mathbf{Q}_{k-1}) \ f^2(\mathbf{Q}_{k-2}) \ \cdots \ f^n(\mathbf{Q}_{k-n})]$$

where $f^n(\mathbf{Q}) = \underbrace{f(f(\cdots f(\mathbf{Q})))}_n$. The function f is defined

by:

$$f(\mathbf{Q}) \triangleq \begin{bmatrix} \cos(d_\theta) & -\sin(d_\theta) \\ \sin(d_\theta) & \cos(d_\theta) \end{bmatrix} \left(\mathbf{Q} - \begin{bmatrix} d_x \\ d_y \end{bmatrix} \right)$$

The example of multi-frame curbs is shown in Fig. 4.

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