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Map-Matching-Based Localization Using Camera and Low-Cost GPS For Lane-Level Accuracy

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Abstract

For self-driving systems or autonomous vehicles (AVs), accurate lane-level localization is a necessity for performing complex driving maneuvers. Classical GNSS based methods are usually not accurate enough to have lane-level localization to support the AV's maneuvers. LiDAR-based localization can provide accurate localization. However, the LiDAR price is still one of the big issues preventing this kind of solution from becoming wide-spread commodities. Therefore, in this work, we propose a low-cost solution for lane-level localization using a vision-based system and a low-cost GPS to achieve high precision lane-level localization. Experiments in real-world and real-time demonstrate that the proposed method achieves good lane-level localization accuracy, outperforming solutions based on only GPS.

Keywords: autonomous driving; lane-level localization; lane detection; GNSS; GPS; map-matching.

1. Introduction

Autonomous driving or drive-less car system is a promising technology for a future transportation that potentially has the capacity to improve road safety and to have a better mobility. Self-driving cars promise to bring a number of benefits to society, including prevention of road accidents, optimal fuel usage, comfort and convenience [1].

In order to perform complex maneuvers, an autonomous vehicle needs an accurate and robust real-time localization. Nowadays, localization has emerged as one of the crucial issues in drive-less cars development[2]. A lot of research has been done over the last decade on vehicle localization systems. The GNSS or global navigation satellite system is one of the most widely used sensors for localizing the vehicle's positions, such as the global positioning system

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(GPS). However, using only GPS solution for the localization system is not optimal to support the AV maneuvers. The accuracy of GPS often degrades due to poor satellite constellation geometry, shadowing, and multi-path propagation of satellite signals [3].

To address the GPS positioning errors, complementary systems depending on dead-reckoning sensors including accelerometer, gyroscope, and odometers have been proposed. However, the systems using these kinds of sensors have some drawbacks. Besides the expensive price issue, their drifts rapidly increase with time, and regular calibration is required [3][4]. To bridge the gaps, fusing sensors such as visual information, digital map, and GNSS to improve localization accuracy of vehicle has emerged as a potential solution and has become one of the hottest issues in the past years [5, 6, 7, 8].

Currently, there is much interest in the vehicle localization based on high-definition maps [2]. Digital map is used as a powerful complementary system for improving the performance of the vehicle localization. It is generated by providing sufficient information to localize vehicle's positions relative to the map.

Common approaches have been proposed involving the combination of LiDARs, IMU, GPS and high resolution digital maps as solutions. Fusing the measurements from vision, GPS and LiDAR have been proposed in [11] and [12]. However, the LiDAR price is still one of the big issues preventing this kind of solution from becoming widespread commodities [13]. Therefore, in this work, we propose a low-cost solution for lane-level localization using a vision-based system and a low-cost GPS to achieve high precision lane-level localization.

The main contributions of this paper are:

- We propose a low-cost localization system using vision-based method;
- We combine map-matching method and low-cost GPS to achieve high precision lane-level localization;
- We carry out extensive experiments in real-time and a real environment.

In general, three major steps are required: creating reference map, finding the corresponding road segment, and positioning the vehicle on the map.

The rest of the paper is structured as follows. Related work is discussed in Section 2. Section 3 presents our proposed approach for localization. Section 4 describes the experiments and discusses the results. Section 5 draws some conclusions and future directions.

2. Related Works

The current localization approaches for autonomous driving can be classified into three types namely LiDAR-based, Camera-based, and Sensor Fusion-based approaches.

Vehicle localization using a probabilistic map and LiDAR has been proposed in [14]. In this work, there are tree phases used for generating the map: they firstly align the overlapping returned laser beam areas, and then perform the calibration to obtain the similar response curves, and finally, make a projection of the aligned calibrated trajectories into a high-resolution probabilistic map. Another LiDAR-based map-matching technique was proposed in [15]. The authors utilized the laser sensor Velodyne HDL 32-E and proposed a localization system based on particle filter. Two map-matching distance techniques have been investigated; a modified Likelihood Field distance and an adaptive standard Cosine distance. A map-matching distance between global maps and compact global map has been used to update the poses of particles. The global map is generated offline using car's odometry, GPS/IMU, and 3D LiDAR data and processed by GraphSLAM method. Meanwhile, the local maps are created online by employing the occupancy grid-mapping algorithm. In [16], the authors also used a Velodyne HDL-32E LiDAR and it is combined with an IMU sensor to get more detail environmental features. In this method, a two-layer LiDAR has been applied. The bottom layer contains of ground curb features, and the upper layer composed of a 2D point cloud of the vertical features. The use a combination between an a-priory map and Monte Carlo Localization (MCL) method to obtain the estimated of the vehicle's position.

Compared to LiDAR, camera-based localization is a low cost solution [17]. Stereo vision-based localization has been proposed in [18], using particle filter to have a system that can locate and navigate the vehicle on the region with the absence of lane line marking. In [19], the authors developed video-based localization technique using point feature-based localization (PFL) and lane feature-based localization (LFL) methods to support the existing GNSS.

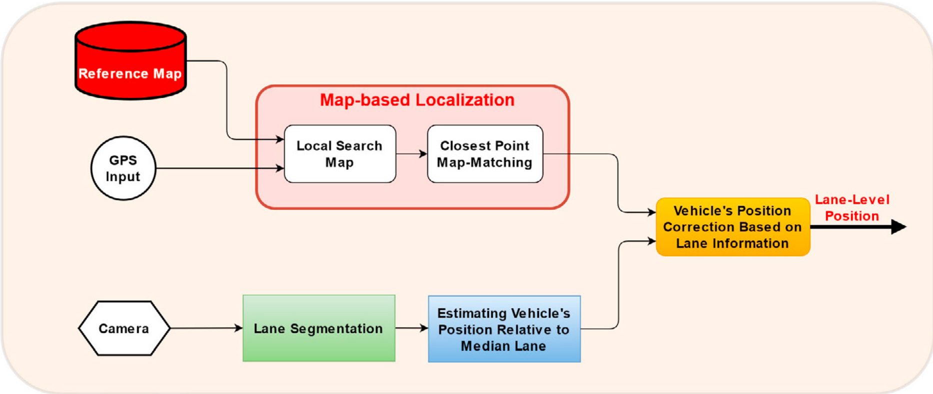


Fig. 1. The pipeline of our proposed system.

These methods are complementing each other. PFL performs better in inner city scenarios whereas LFL is good in rural areas.

Localization based on sensor fusion has been applied in [20]. The GNSS, LiDAR, and IMU sensors have been fused adaptively. The system uses Kalman filter to integrate the GNSS, SLAM and inertial navigation. The local map matching method is used to eliminate the accumulated error and to correct the positioning system. Fusing the measurements from vision, GPS and LiDAR has also been proposed in [11] and [12].

The high cost of LiDARs limits LiDAR-based localization for being widely used in wide-spread commodities [13]. On the other hand, the low-cost and promising performance in autonomous driving applications, vision-based approaches have shown to be appealing in solving the lane-level localization problems for autonomous driving vehicles. Therefore, we further explore vision-based technologies for developing a novel low cost lane-level localization approach.

3. Our Proposed Approach

In this work, we propose an elegant method using map-matching technique to obtain high lane-level localization accuracy. The framework of the proposed method is presented in Figure 1. Our method takes three inputs: Camera, GPS, and a Reference Map.

The GPS point constituting the trajectory is given as follows:

$$\mathbf{p}_w = (p_{x_w}, p_{y_w}) \tag{1}$$

where p_x and p_y represent the longitude and latitude coordinates, respectively, and w is the current window timestamp.

The reference map positions $\mathbf{r}$ can be defined as follows:

$$\mathbf{r}_j = (r_{x_j}, r_{y_j}) \tag{2}$$

where r_x and r_y represent the longitude and latitude coordinates, respectively, and j is the location number of the reference point.

The GPS provides the local positions and creates a local search map for an area of $25m$x$25m$. The reference points of local map are selected from the reference map whose the points fall inside the local area where the current GPS

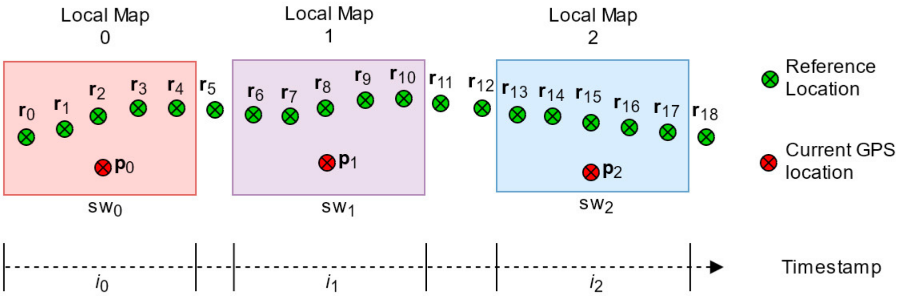


Fig. 2. Illustration of Map-matching process using sliding window (sw_i)

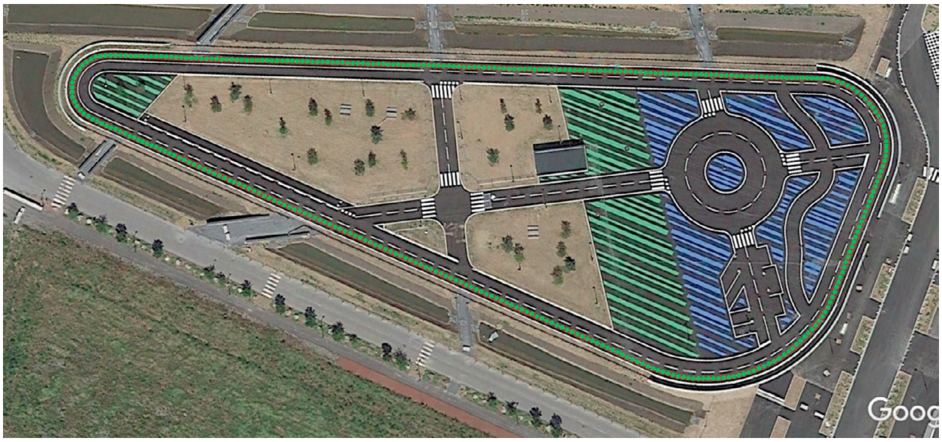


Fig. 3. Reference map

position is currently located. Therefore, the local reference of the window timestamp $\mathbf{r}^w$ can be defined as follows:

$$\mathbf{r}_k^w = (r_{x_k}, r_{y_k}) \tag{3}$$

where k is the location number of the reference point in the local map area.

The distance between these points and the current local GPS position are calculated and compared using the simple closest point algorithm.

Using sliding window technique, as shown in Figure 2, we search for the closest point (**CP**) between the position acquired from the current GPS and the positions in the reference map where the vehicle passes through it. The distances are calculated using Euclidean distance. The minimum distance is selected as the most appropriate position that is close to the vehicle. The closest point for a corresponding window is determined by the following relation:

$$\mathbf{CP}_{\mathbf{p}_w}^w = \mathbf{r}_j^w, \quad \xrightarrow{where} \quad \underset{j}{\operatorname{argmin}} \left\{ \sqrt{\sum_{t=1}^{2} \left(p_{wt} - r_{jt}\right)^2} \right\} \tag{4}$$

Simultaneously, the camera supplies the sequence of images to be processed by lane segmentation algorithm. Using lane segmentation we have vehicle's position relative to median lane.

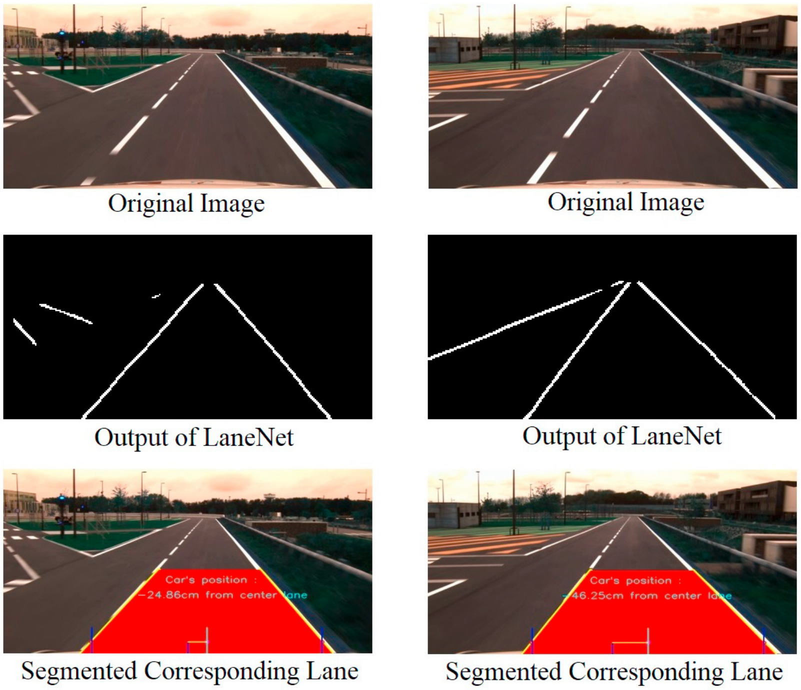


Fig. 4. Process of finding the corresponding road segment

3.1. *Creating the Reference Map*

The reference of our map is created by leveraging Google Earth Pro. In early 2015, Google Earth Pro costed about \$400, and now it is free to use [10]. We firstly created the center lane path and saved it into KML format. Then, we extracted the coordinates of this path and stored them as our reference map of the center lane. Figure 3 shows the reference map used in this work created by using Google Earth Pro.

3.2. *Finding the Corresponding Road Segment*

Roads are multi-lines. Usually, the left and right road boundaries are represented by two multi-lines. The road marks separating lanes are also shown by multi-lines. A single lane of a multi-lane feature is called road segment.

One of important steps of this approach is to localize the corresponding road segment from the input image. For this work, LaneNet [9] is employed to produce the lane segmentation. We use binary image output of the LaneNet and perform post-processing. The result of LaneNet is in form of multi-line based upon the number of road segments. In order to obtain the corresponding lane, output of LaneNet requires further processing to find the correct road segment, which is the segment where the vehicle is passing through it. To do so, we use a simple technique involving line Hough transform in order to obtain multi-line on the image. We divide the image into two sides, left and right and then we select one line on the left side and one line on the right side whose their bottom positions are closest to the bottom center of the image. These two lines are supposed to be the borders of the corresponding lane. Figure 4 shows the examples of the process of obtaining the corresponding road segment.

3.3. *Vehicle Position on the Map*

After the implementation of the closest point map-matching method, we estimate the final position of the vehicle that is the position relative to the median lane. Figure 5 clearly illustrates the relation between the center of vehicle and the median lane. The estimated distance of the center of vehicle relative to the median lane is formulated as follows:

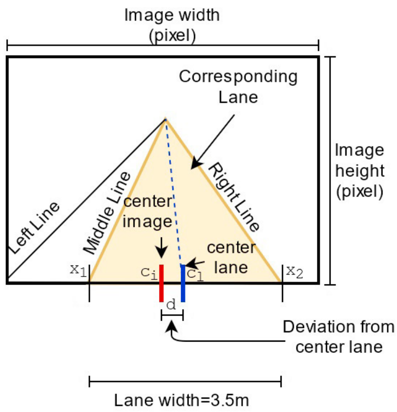


Fig. 5. Description of how the deviation distance between the center of vehicle and middle lane is obtained

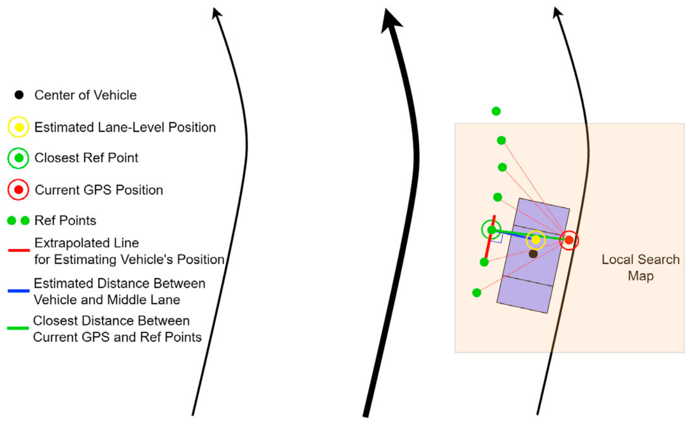


Fig. 6. Illustration of estimating vehicle's position based on map-matching

$$\mathbf{d}_m = \frac{LaneWidth_m}{(x_2 - x_1)_{px}}\, \mathbf{d}_{px} \tag{5}$$

where $\mathbf{d}_m$ is the estimated distance of the center of vehicle relative to the median lane in *meter*, $LaneWidth_m$ is the width of the lane in *meter*, $(x_2 - x_1)_{px}$ is the width of the lane in *pixel*, and $\mathbf{d}_{px}$ is the estimated distance of the center of vehicle relative to the median lane in *pixel*.

Using the estimated distance between the center of vehicle relative to the center lane, the lane-level localization is performed as shown Figure 6.

4. Experiments and Results

Our proposed approach was tested in a track whose length is 850 meters. The track is composed of two lanes of width of 3.5 meters each. The current position of the vehicle is measured using a low cost GPS receiver mounted on the top of a testing car. When conducting the experiments, we do not have a high precision GPS used as a ground-truth data. This way we measured the deviation of distance from the middle lane to the center of the vehicle. By assuming

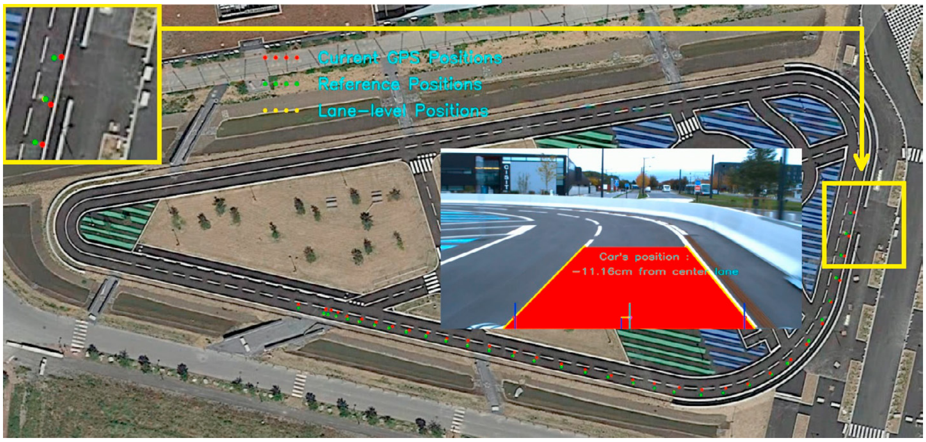
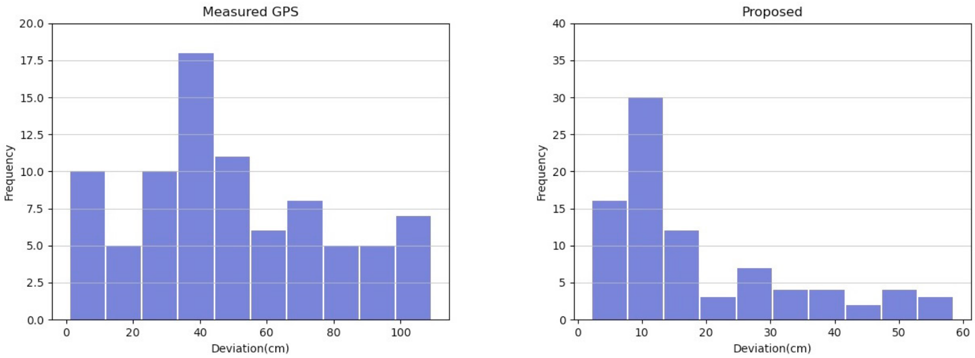


Fig. 7. Qualitative localization result of the proposed method



a) b)

Fig. 8. Histogram of deviation between the center of vehicle and the median lane using: a) the only GPS system and b) the proposed method.

that the vehicle should most of the time be in the middle lane, we measured vehicle's position relative to the median lane as our performance metric. Table 1 shows the preliminary results of the comparison between the GPS positioning and the estimated position obtained using our proposed method. The qualitative result of the experiments can be seen in Figure 7.

Table 1. Performance comparison between the GPS positioning and the estimated position obtained using our proposed method.

	Deviation in measured position	**Deviation in estimated position**
Mean (cm)	49.30	29.52
Standard deviation (cm)	18.65	14.53

Based on Table 1, the measured GPS position has higher variance and higher mean values than the estimated position. This indicates that the GPS measures are not accurate enough to localize the position of the car. Compared to the measured GPS, our proposed estimated position has smaller mean and variance values. This indicates that the proposed method works better than the only GPS approach. This also indicates that most of the times the vehicle follows the median lane. The comparative results can also be seen in Figure 8. It is clear that the proposed method localizes the vehicle more accurately than using only GPS.

5. Conclusion

In this paper, we proposed a low-cost solution for a localization system using vision-based system combined with map-matching method and a low-cost GPS to achieve high precision lane-level localization. In general, three major steps are required: creating reference map, finding the corresponding road segment, and positioning vehicle on the map. Our proposed approach was applied for real-time measurement of vehicle's position relative to median lane. The preliminary results showed better performance compared to measured GPS position.

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