Preliminary Study for Low-Cost Curb Detection Using Multiple Ultrasonic Sensors

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BIOGRAPHY

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ABSTRACT

Technologies related to autonomous driving are drawing significant attention these days, and many international automobile companies are developing autonomous cars. Among various autonomous driving technologies, environmental recognition is one of the core technologies. The environmental recognition of self-driving vehicles means perceiving the nearby driving environment, such as other vehicles, people, traffic lights, road signs, and curbs. This paper focuses on curb detection. The curb is a useful feature for self-driving vehicles to distinguish the boundary between street and sidewalk. Once the distance between the curb and the vehicle is measured, the current driving lane can also be determined. In addition, the curb information can be used for safety, by preventing the autonomous car from intruding into the sidewalk. Previous curb detection methods have mostly relied on the LIDAR sensor, which provides precise distance measurements; but the sensor price is very high. For this reason, the curb detection system has not yet been commercialized at an affordable price.

This paper performs a preliminary study to develop a curb detection system for self-driving vehicles using ultrasonic sensors, which is a very low cost solution. Although the price of an ultrasonic sensor is significantly less than other distance measuring sensors, such as LIDAR or RADAR, the accuracy and reliability of the ultrasonic sensor is relatively low. However, the use of multiple ultrasonic sensors with optimized filters and algorithms may support the curb detection application. In this paper, we implement a hardware platform with multiple ultrasonic sensors, and propose a preliminary algorithm for curb detection. The algorithm utilizes Kalman filtering for preprocessing, which calculates the real distance value from raw measurements based on the system model. Then, the preprocessed measurements from multiple sensors are weighted and compared for decision making. We demonstrate the preliminary performance of the suggested system based on the actual measurement data from road tests.

Keywords: Autonomous Driving Vehicle, Environmental Recognition, Curb Detection, Ultrasonic Sensor, Kalman Filter

INTRODUCTION

There are several categories of autonomous driving technologies: environmental recognition, localization and mapping, decision and control, and communication and interaction. Environmental recognition is the core technology, because of its important role in the autonomous driving vehicle. Environmental recognition is a technology that uses various sensors to detect and determine objects around the vehicle. There are many kinds of objects that environmental recognition technology has to cover, which include the road, traffic lane, other vehicles and pedestrians to avoid, traffic lights, signs, and roadside curbs.

Compared to other road-side infrastructures, curbs, the concrete borders or rows of joined stones that are formed along the edge of a street, have only relatively recently received attention. The curb is a useful feature for autonomous driving, because it distinguishes the boundary between street and sidewalk. For example, the distance between the curb and the vehicle can be used to determine the current driving lane. Also, it can be helpful to prevent vehicles from accidents like intrusion into the pedestrian way. Therefore, various groups are currently researching curb detection technology. Fernandez et al. [1] suggested a curvature-based curb detection method in urban environments using stereovision and laser. Duan et al. [2] presented a curb and other obstacle detection system with four-line LIDAR. Chen et al. [3] advanced a novel curb detection algorithm that could detect curbs up to 50 meters away. While there are numerous published researches about curb detection and its implementation, there share one common feature: most of these researches use LIDAR as the main sensor.

LIDAR is a sensor that is commonly used to detect surrounding environments by sensing optical pulses. It is a powerful sensor for autonomous cars, due to its high accuracy, wide range, and 360° viewing angle. But there are two disadvantages to using LIDAR for autonomous cars. The first is price. For example, a general 64 channel LIDAR costs over tens of thousands of dollars. So while multiple LIDARs might be needed, it may not be practical to use them. Also, the blind spot that can be formed while using a single LIDAR is an additional problem. Second, LIDAR cannot operate normally in bad weather conditions. Because it senses environments with an optical laser, raindrops, snowflakes, or fog can disturbed it. Recently, Ford is attempting to get over this weather constraint by loading 4 LIDARs on the roof [4], but so far, the use of LIDAR in harsh weather doesn't seem to be cost-effective. For these reasons, LIDAR is not considered a perfect sensor for autonomous cars; and therefore other sensors are expected to perform a complementary role and substitute for LIDAR.

The ultrasonic sensor is a typical low-cost sensor that measures distance to an obstacle by ultrasonic waves. In this paper, we suggest a curb detection system for autonomous driving using ultrasonic sensors. Ultrasonic sensors are definitely cheaper than other sensors such as LIDAR. So they can lower the price of the system, and increase price competitiveness. Also, there are disadvantages to using ultrasonic sensors. The major problem is their relatively low quality and accuracy of measurement. There are definite limitations to the hardware performance that can be obtained from a single ultrasonic sensor. The way to overcome the problem is to increase the accuracy with software solutions, such as filters and algorithms.

In this paper, we first introduce the hardware platform of the curb detection system that we implemented. Section II describes the hardware structure sensor devices. Section III introduces software and its filtering algorithm that improves the performance of the system. In particular, we describe the system model and Kalman filter design in detail, and present the results of a performance test in the real-time experiment we performed. Section IV concludes the paper.

HARDWARE PLATFORM IMPLEMENTATION

The hardware of the curb detection system consists of multiple ultrasonic sensors. Using multiple sensors enables confidence checks, and excludes measurements with low quality. In this system, we equipped 4 ultrasonic sensors at the right side of the vehicle, where the curb can be in their line-of-sight. The tilt angle of each sensor could be precisely adjusted to view the curbs. Each sensor measured the distance to the curbs at a 10 Hz rate. The frequency of the ultrasonic wave was 40 kHz, and the maximum measurement range of the sensors was about 10 meters.

(a) (b)

Fig. 1. (a) Hardware platform installed on the test vehicle, and (b) the implemented single ultrasonic sensor.

PRELIMINARY ALGORITHM AND FIELD TEST RESULTS

There are more noise sources in the driving situation than in a laboratory environment. Distance measurements from sensors are collected with heavy noise due to vehicle vibration, wind flow, relative velocity of target, etc. We adopted a Kalman filter to estimate the correct value from the inexact measurements. The filter eliminates most of the errors from the measurements by prediction and estimation based on the system model. We can represent the system model of measuring distance with ultrasonic sensors as Eq. (1).

$$\begin{cases} x_{k+1} = Ax_k + w_k \\ z_k = Hx_k + v_k \end{cases} \tag{1}$$

Vector x_k is $[d_k \quad v_k]^T$, where d_k is the distance, and v_k is the rate of change in d_k. w_k is the noise vector caused by the external environment, and v_k is the noise vector caused by the sensors. z_k is the filter input, which is the real measured distance data from the sensors. Matrix A and H in Eq. (1) are set as below, because the desired output of the sensor is the range measurement, d_t and v_t is the derivative of d_t.

$$A = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix}, \quad H = \begin{bmatrix} 1 & 0 \end{bmatrix} \tag{2}$$

From the basic definition of the Kalman filter, we can write the state estimate and estimate covariance of prediction as Eqs. (3) and (4) [5].

$$\hat{x}_{k|k-1} = A\hat{x}_{k-1|k-1} \tag{3}$$

$$P_{k|k-1} = AP_{k-1|k-1}A^T + Q \tag{4}$$

There are various notations for a Kalman filter; but in this paper, $\hat{x}_{k|k}$ means the a posteriori state estimate value at time k obtained from given observations up to time k, and $P_{k|k}$ means the a posteriori error covariance matrix. Matrix Q in Eq. (4) is a covariance matrix of w_k. Then we can represent the optical Kalman gain as Eq. (5).

$$K_k = P_{k|k-1}H^T(HP_{k|k-1}H^T + R)^{-1} \tag{5}$$

Matrix R in Eq. (5) is a covariance matrix of v_k. Finally, we can derive the updated state estimate and estimate covariance as Eqs. (6) and (7).

$$\hat{x}_k = A\hat{x}_{k-1|k-1} + K_k(z_k - HA\hat{x}_{k-1|k-1}) \tag{6}$$

$$P_k = P_{k|k-1} - K_k HP_{k|k-1} \tag{7}$$

Figure 2 shows the measurements passed through the Kalman filter. We perform the experiment by driving straight alongside the curb, and maintain the velocity of the vehicle at 40 km/h. There are steep fluctuations between measurements because of the driving situation, but the Kalman filter reduces the noise, and estimates the original distance.

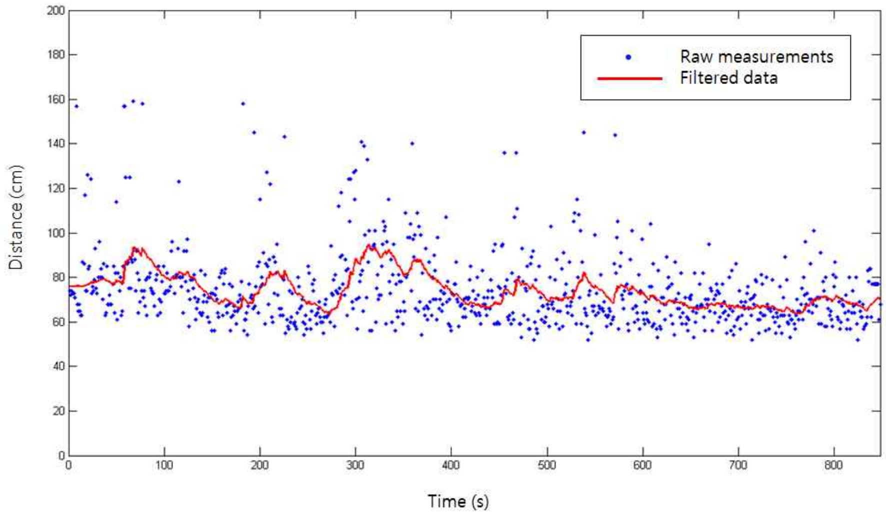

Fig. 2. Raw measurement and outputs from the adopted Kalman filter.

CONCLUSION

In order to develop a practical curb detection system, it is important to develop a powerful algorithm that can increase the performance of ultrasonic sensors. Accordingly, a basic hardware platform is needed that can load and test various curb detection algorithms. In this paper, we build a hardware platform with multiple ultrasonic sensors, and also propose a preliminary algorithm for curb detection. We base the algorithm on a Kalman filter, and modify it for use in an autonomous driving application. Our field experiment results show that the algorithm stably detects the curb. But more complex and robust algorithms are necessary to detect curbs in various harsh circumstances. In future work, we plan to suggest and test various algorithms on the hardware platform we have developed.

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