Pothole Detection System using 2D LiDAR and Camera

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***Abstract*— Automatic Pothole detection is important task for determining proper strategies of asphalt-surfaced pavement maintenance. In this paper, we develop a pothole detection system and method using 2D LiDAR and Camera. To improve the pothole detection accuracy, the combination of heterogeneous sensor system is used. By using 2D LiDAR, the distance and angle information of road are obtained. The pothole detection algorithm includes noise reduction pre-processing, clustering, line segment extraction, and gradient of pothole data function. Next, image-based pothole detection method is used to improve the accuracy of pothole detection and to obtain pothole shape. Image-based algorithm includes noise filtering, brightness control, binarization, addictive noise filtering, edge extraction, and object extraction and pothole detection. To show the pothole detection performance, experiments of pothole detection system using 2D LiDAR and camera are performed.**

Keywords—pothole detection; 2D LiDAR; camera

I. INTRODUCTION

The occurrence of pothole has increased rapidly in extraordinary weather such as heavy rain in summer and snowfall, and has a great influence on traffic safety and road damage. It causes social problems such as vehicle breakage and accidents, which are causing social costs. Therefore, automatic pothole detection methods are being studied for efficient pothole repair and pavement management.

Existing methods for pothole detection can be divided into vibration-based methods, 3D reconstruction-based methods, and vision-based methods [1-3]. Vibration-based method uses accelerometers in order to detect potholes. However, vibration based methods could provide wrong results that the hinges and joints of road can be detected as potholes. 3D reconstruction using laser scanning systems can detect potholes in real time. However, the cost of laser scanning equipment is still significant. Although the vision-based methods are cost effective than 3D laser scanner methods, it may be difficult to recognize pothole due to noise in a form similar to pothole such as shadow, road surface patch.

Light Detection and Ranging (LiDAR) obtains the distance information based on the time when the infrared ray comes back from the object. Laser measurement is used in various fields such as autonomous vehicles, global environment observation, atmospheric analysis, unmanned aerial vehicles, and space facilities. Recently, LiDAR-based three-dimensional mapping technology has been actively studied, and it is applied in various fields such as distance measurement, autonomous running, and quadcopter.

For video-based pothole detection, open source computer vision (OpenCV) is used. OpenCV is a library of real-time computer imaging programs. This open source computer vision code is used in applications such as object, face, behavior recognition, and motion tracking. It is useful to detect that contains many image functions supports the development of computer vision applications.

2D LiDAR and Camera based pothole detection system has the advantage that is not affected by the electromagnetic wave and the road surface state. Hence, we develop an automatic pothole detection system using 2D LiDAR and camera that is cost effective solution.

II. POTHOLE DETECTION SYSTEM

We consider a pothole detection model that is shown in Fig. 1. A rectangular pothole has the width, length and depth as 30 cm, 30 cm, and 15 cm, respectively. Two 2D LiDARs are installed 1 m above the road and two LiDARs are 1 m apart, and scan axis of 2D LiDAR is orthogonal to the road surface. One camera is also installed 1 m above the road and is located at the center between two LiDARs. 2D LiDAR system collects pavement surface distance data across a 4 m wide pavement, and

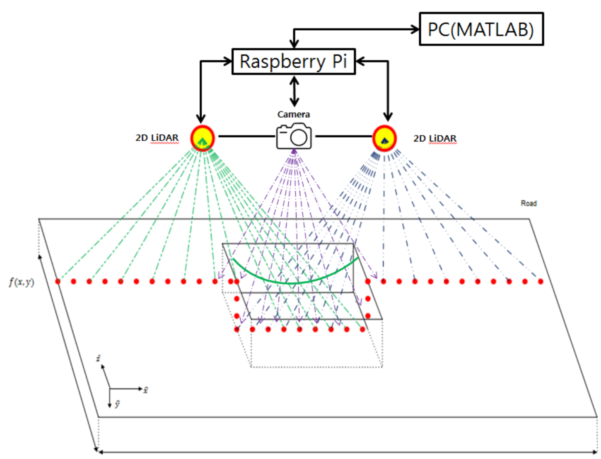


Fig. 1. Pothole detection model

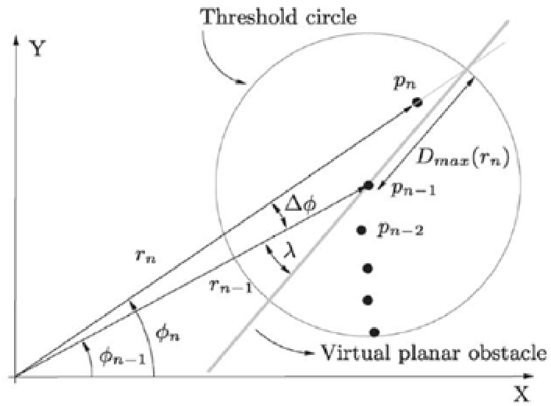


Fig. 2. Adaptive breakpoint detection

scanning frequency of LiDAR is 5.5 Hz when sampling 360 points each round. In addition, we collect 30 times pavement surface scanning data for accurate pothole detection. The Camera is used to collect and store pothole video data.

A. 2D LiDAR based pothole detection method

For accurate pothole detection using 2D LiDAR, four steps including filtering, clustering, line extraction and gradient of data function are performed. First, filtering operation is performed because the collected LiDAR data contains noisy distance data. Hence, noise reduction using median filter is used and it is pre-processing step to improve the pothole detection probability. For each angle, median value is the middle value after all the entries in the window are sorted numerically.

Next, the point cloud data of the LiDAR sensor can be clustered by obtaining the distance between two adjacent points and calculating the break point using an appropriate threshold value. As shown in Fig. 2, adaptive breakpoint detector (ABD) is a method that can construct clustering based on D_{max}. The following equation (1) is an expression for obtaining D_{max}.

$$D_{max} = r_{n-1} \cdot \frac{\sin(\Delta\emptyset)}{\sin(\lambda - \Delta\emptyset)} + 3\sigma_r \tag{1}$$

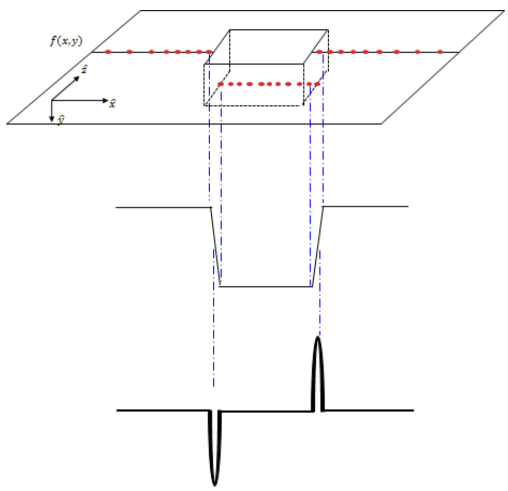


Fig. 3. Variation in the slope of the road

where λ and σ_r are parameters that the user can define. As λ is small or σ_r is larger, the influence range of clustering becomes wider. In order to recognize P_n as a breakpoint by the ABD algorithm, the value of $|p_n - p_{n-1}|$ must be larger than the value of D_{max}. If it meets the condition, the points $p_1 \sim p_n$ are handled as one cluster [4].

After clustering about point cloud data, line segment extraction is performed. The iterative end point fit (IEPF) algorithm is used for the line segment extraction [2]. Next, the gradient of the data function is performed to decide the existence of pothole. In Fig. 3, $f(x, y)$ is the pothole data function after line extraction. In order to decide that $f(x, y)$ is pothole or not, first order differentiation of $f(x, y)$ is performed. If there is a pothole, the differential waveform of $f(x, y)$ has abrupt change in the function. $P(x_1, y_1)$ is the first point which has abrupt change in differential waveform, and $P(x_n, y_n)$ is the final abrupt change point. When pothole is existing, the width and depth of the pothole is obtained like as

$$\text{Width} = \sqrt{(x_1 - x_n)^2 + (y_1 - y_n)^2} \tag{2}$$

$$\text{Depth} = |P_{ymax} - P_{ymin}| \tag{3}$$

where P_{ymax} and P_{ymin} are the maximum and minimum y values respectively.

B. Vision based pothole detection method

An image-based porthole detection system can improve detection accuracy and reduce cost compared with laser scanning method. A porthole detection system using a black box image can be easily installed in a vehicle, and if the detection algorithm is developed with a light weight, it can be mounted in a general black box. The image-based pothole detection algorithm has total of seven stages as shown in Fig. 4 [5].

First, the noise of the image is removed. Since the initial image input from the black box is data exposed to various noises, noise filtering must be performed before the image analysis. Image noise removal uses Gaussian blurring algorithm to remove noise. By removing the noise, the contrast of the image can be improved by adjusting the brightness of each region, which makes it easier to separate the background from the potholes.

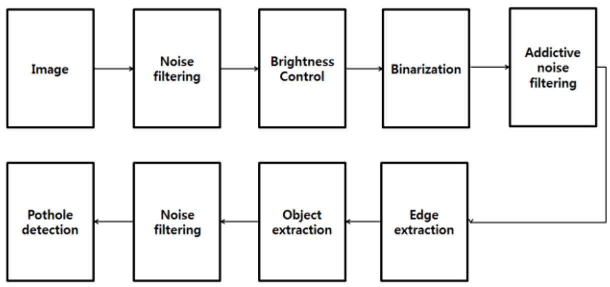


Fig. 4. 7 Stage of pothole detection algorithm

Next, we adjust brightness to improve the contrast of an image. Binarization is performed to simplify pothole within an image by shape and size information. After noise filtering, we obtain pothole within the image. Next, the edge of segmented object on the binary image is extracted. Finally, the detected pothole within the image is obtained.

III. EXPERIMENT

Two 2D LiDAR, called as RPLIDAR, and a camera are connected to the Raspberry Pi 3 small single-board computer. The RPLIDAR is the low cost 360 degree 2D laser scanner. Each LiDAR sends information such as the distance to the object, angle, and accuracy using serial communication to the single-board computer. After obtaining LiDAR information, proposed pothole detection algorithm is performed using MATLAB. Estimated pothole information such as width and depth are compared with those of the actual pothole information. Error rate about width and depth of the pothole can show the effectiveness of the proposed pothole detection algorithm.

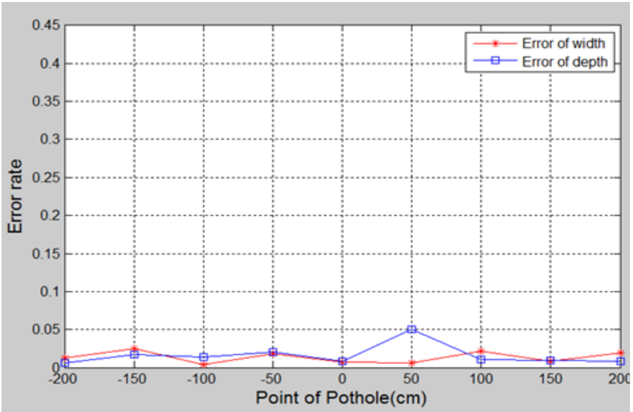


Fig. 5. Error rate of pothole detection using two LiDAR

Fig. 5 shows the error rate of pothole detection when two LiDARs are used. The error rates of pothole detection maintain low enough even though the position of pothole is moved away from the center of the road. Fig. 6 show the 3D pothole shape using 2D LiDAR by moving the pothole detection system with 2.7 km/h.

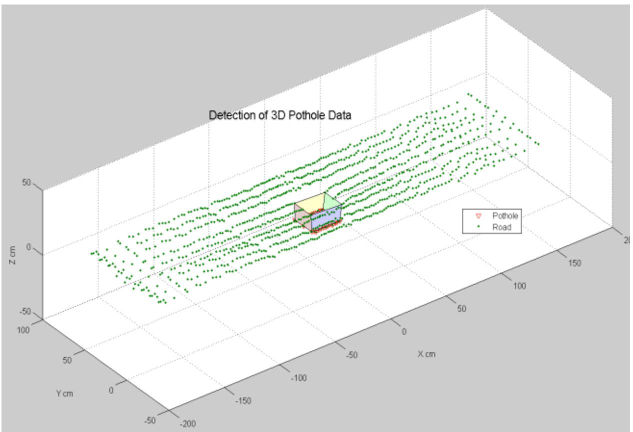
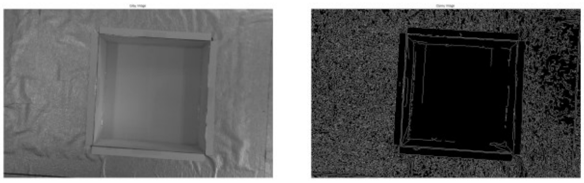


Fig. 6. 3D pothole detection using 2D LiDAR



(a) Color to gray Image (b) Canny edge detection

Fig. 7. Edge extraction of pothole image

Pothole detection using 2D LiDAR are compared with pothole detection using video data. Fig. 7 shows pothole image and edge extraction of pothole image using canny edge detection algorithm. Next, we make a square zone for the object as region of interest. By combining heterogeneous data, we can get more accurate pothole information.

IV. CONCLUSIONS

In this paper, we developed a pothole detection system using 2D LiDAR and camera. By using two LiDARs, wide area of the road surface can be scanned more accurately. Next, we developed pothole detection algorithm including filtering, clustering, line extraction and gradient of data function. Error rate of pothole detection system shows the performance of developed system. We also showed 3D pothole detection can be performed using 2D LiDAR. Pothole detection using video data is combined with that of 2D LiDAR, and combined data gives more accurate pothole detection performance.

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