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Road Pothole Detection System Based on StereoVision

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Abstract**—**The pothole is an useful thing for drivers. The pothole can cause accident. To detect and repair the pothole is more important. But it is difficult to find the pothole. We propose a stereo vision system which detects potholes during driving. The main aim is to benefit drivers to take action to potholes in advance. This system contains 2 USB cameras click photo simultaneously. We calculate the disparity map by using parameters obtained from camera calibration with checkerboard.2-dimensional image points can be projected to 3-dimensional world points using the disparity map. With all the 3-dimensional points, we use the bi-square weighted robust least-squares approximation for road surface fitting. All the points that are below the surface of road model can be detected as pothole region. The size and depth of each pothole can be obtained .The experiments we conducted show robust detection of potholes in different road and light conditions.

Index Terms—road potholes, stereo vision, surface fitting,

I. Introduction

Potholes are in shape of bowl openings on the road that can be up to 12 inches in depth and are caused by the wear-and-tear and weathering of the road . They appear when the top layer of the road, the bitumen, has worn away by lorry traffic and exposing the concrete base. Once a pothole is formed, its depth can increase to several inches, with rain water accelerating the process, making one of the top causes of car accidents. The main cause of car accidents are not only pothole, but also can be fatal to motorcycles. Potholes on roads are dangerous for drivers when drift in high speed. Because, the driver can hardly see potholes on road surface. Even though drivers may see the pothole before they pass it, it is usually too late to react. It may causes rollover due to any sharp turn or suddenly brake.

From the above reasons, we investigate a system to detect potholes on roads while driving. The system will produce the 3-dimensional information of potholes and determine the distance from pothole to carfor informing the driver in advance.

Currently, the main methods for detecting potholes still rely on public reporting through hotlines or websites. However, this reporting usually lacks accurate information of the dimensional and location of potholes . Moreover, this information is usually out of date aswell.

A method to detect potholes on road has been reported inareal-time3Dscanningsystemforpavementdistortion inspection which uses high-speed 3D transverse scanning techniques. However, the high-speed 3D transverse scanning equipment is too expensive. Have proposed a cost-effective solution which using ultrasonic sensors to identify the potholes on roads, and to measure the depth and height of each pothole. All the pothole information is stored in database. Then in the form of a flash messages alerts are provided with an audio beep through android application. To detect the depth of pothole correctly, the ultrasonic sensor should be fixed under the car, which meansthecarshouldpassthepotholefirst.2D vision-based solutions can also be detect by potholes a. The potholes are represented in a matrix of square tiles and the estimated shape of the pothole is determined. In whatever way, the 2D vision-based solution can work only under uniform lighting conditions and cannot obtain the exact depth of potholes.

To remove the drawback of the above approaches, we propose which provides 3-dimensional measurements detection method based on computer stereo vision. Therefore, the geometric features of potholes can be determined easily based on computer vision techniques. The proposed method requires two cameras to click photos simultaneously. Compared with the expensive high-speed 3D transverses canning equipment,USB cameras are affordable and flexible .The geometrical information of road potholes can be obtained by the stereo camera.

There are different section which include different work section 2 briefly discusses the background of this work .Section3 introduces the technical approach and principles that we applied in this pothole detection system. Section 4 illustrates the experimental setup of the proposed system and results. Finally, section 5 concludes the proposed method and discusses the future work which can be done to improve the pothole detections system.

II. Background

By using Zhang's camera calibration method Stereo camera parameters, including intrinsic parameters and extrinsic parameters, are obtained with a checkerboard. Some preparation work needs to be done before converting t image coordinates to the world coordinates,.

Image pairs of road surface should be undistorted and rectified .In undistorted images lens distortion has been removed. Rectification refers to projecting image pairs onto a common image plane, respectively. The rectified and undistorted image pairs are used to calculate the disparity map using the stereo camera parameters obtained before with the semi-global matching algorithm provided in OpenCV (Open Source Computer Vision Library).For compensating radiometric differences of the stereo image pairs this algorithm uses a pixel wise mutual Information-based matching cost.

The disparity map illustrates the corresponding pix- else difference in a pair of stereo images. Thus, with the disparity map, image points can be transferred to world points. The road surface is fitted using the bisque weight edrobust least-squares algorithm with all the points in world coordinate of the road surface image .All the points below the road surface correspond to the pothole region. If there are more than one pothole in the region of interest, pothole points are labeled into different potholes according to their connections using the connected component labeling algorithm.

III. Approach to Pothole DetectionSystem

A. Overview of Pothole Detection System

In this part, we introduce the proposed road pothole detection system. It consists of 2 modules: Offline processing and online processing. The offline flow chart of the proposed system is illustrated in Figure1. Stereo camera parameters, including intrinsic parameters and extrinsic parameters, are obtained using a checkerboard based on Zhang's camera calibration method. The online flowchart of the proposed system is shown in Figure2. There are 3 main modules: Image processing, disparity calculation and pothole detection. Before transferring the image coordinates we have to do some work. The 3 modules will be discussed in following section.

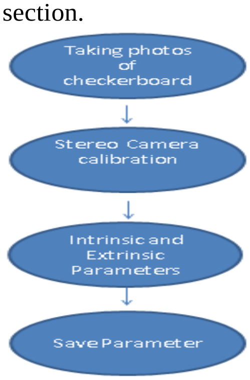


Fig. 1.Offline Flowchart of the Pothole Detection System.

B. Stereo Camera Calibration

As we know Camera parameters are necessary for disparity calculation. We can obtain, both intrinsic and extrinsic parameters, by stereo camera calibration. To calibrate stereo cameras, a flexible camera calibration approach proposed by Zhang is used in this system. The method which we proposed uses economical and flexible equipment.

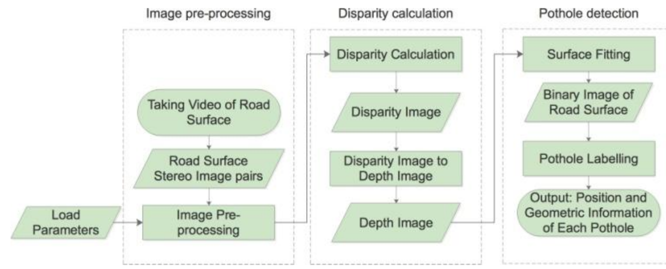
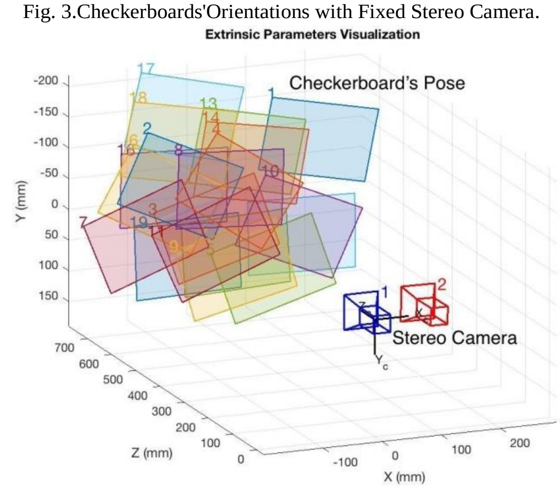


Fig. 2.Online Flowchart of the Pothole Detection System.

We use twoUSB cameras for the observation of checkerboard in different orientations. Proposed system uses an 8X6 checkerboard with 24.5 mm squares. Either checkerboard or the cameras can be moved freely. As theoretical, 2 or more orientations are needed for camera calibration. But we uses, 20 orientations in this system for better quality and performance. Figures 3 and 4 shows the relative movement between the checkerboard and the stereo

Fig. 3.Checkerboards'Orientations with Fixed Stereo Camera.



camera pair considered the different frame of reference. All checkerboards orientations regarding the fixed stereo camera pair are shown in Figure 3.

From the camera calibration process we can be obtained the stereo camera parameters (intrinsic and extrinsic). The intrinsic parameters, are independent and named camera matrix also. Therefore, once the intrinsic parameters are determined, they can be used as long as the focal length of the camera remain unchanged. The output 3X3 camera matrix is shown as follows:

$$A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}.$$

f_x, f_y are the focal lengths expressed in pixel units. (c_x, c_y)

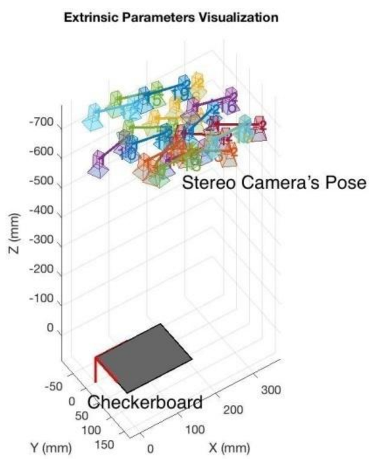


Fig. 4.Stereo Camera's Orientations with Fixed Checkerboards.

is the principal point that is mostly the center of the image. The joint rotation-translation matrix is called extrinsic matrix. Extrinsic parameters can translate a point(X,Y,Z)to the coordinate system with fixed camera. The translation is illustrated by the following:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + t.$$

R is the rotation matrix. t is the translation vector. The joint of rotation-translation matrix Rt is the extrinsic matrix. It can transfer image-coordinate points X, Y, Z toworld-coordinate points,x y, z. The pre-processing work including removal of lens distortions and rectification of the stereo image pairs should be done with both intrinsic and extrinsic parameters. Also, light correction can be added to remove the influences caused by lighting condition. Therefore, the stereo image pairs can be turned into standard form whose corresponding points located at same horizontal line.

C. Disparity Calibration

We use computer stereo vision based methods to detect potholes on road surfaces .Stereo vision is an attempt to simulate human beings.

As shown in Figure 5,for the single camera, we take two different real points P and Q project to a same point in the image plane when they are located in the same line with the optical center. Despite that, when it comes to stereo vision, as shown in Figure 6, if we can find the corresponding pixels in the stereo image pairs, we are able to obtain the depth by means of triangulation.

As shown in Figure 7, the B is the distance between the 2 cameras 'optical centers. $f$is the focal length obtained from stereo camera calibration. XLR and X-OL-OR are equivalent triangles. We can write their equivalent equation as following:

$$\frac{B}{z} = \frac{B + XR - XL}{z - f}.$$

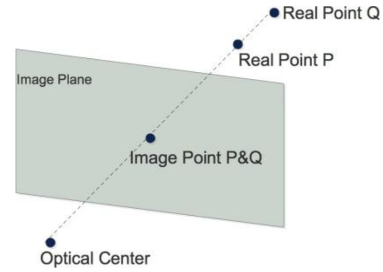


Fig. 5.Single Camera.

Therefore, we can calculate using following equation:

$$z = \frac{B * f}{XL - XR} = \frac{B * f}{d}$$

$z$is the depth of point X, and it is inversely proportional to the disparity. So once we find the corresponding points in the stereo image pairs, we can calculate the disparity and the depth of are alpointon roads correctly.

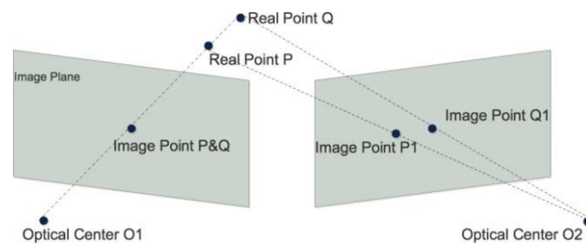


Fig. 6. Stereo Camera.

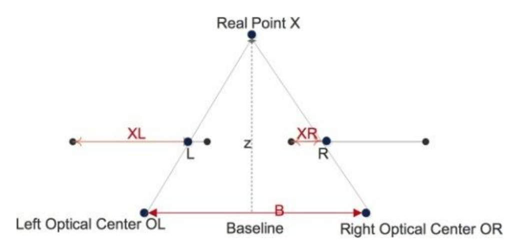


Fig. 7.depthcalculation.png.

The main difficulty is how to find the best corresponding points in the stereo image pairs. In this paper, we use the semi-global Matching algorithm proposed by Heiko which is provided in OpenCV.

D. Image Reprojection

We can use a triangulation method to reproject the disparity image to 3D space. For the stereo cameras, given the disparity image and the camera parameters like camera's focal length, we can calculate the 3-D coordinates in real world.

As shown in Figure 8, the optical center of camera L is the origin. $f$is the focal length of the camera. Triangle OAE and triangle OMP are similar triangles, therefore we can write:

$$\frac{z}{f} = \frac{x}{XL}. \quad (5)$$

For the right camera, triangle OCD and triangle ONP are similar triangles:

$$\frac{z}{f} = \frac{x-B}{XR}. \quad (6)$$

Similarly, along the Y- axis, we can obtain:

$$\frac{z}{f} = \frac{y}{YL} = \frac{y}{YR}. \quad (7)$$

The 3 dimensional points as a function of the disparity can be derived from the above equations and equation (4):

$$x = \frac{B*XL}{d}, \quad (8)$$

$$y = \frac{B*YL}{d}. \quad (9)$$

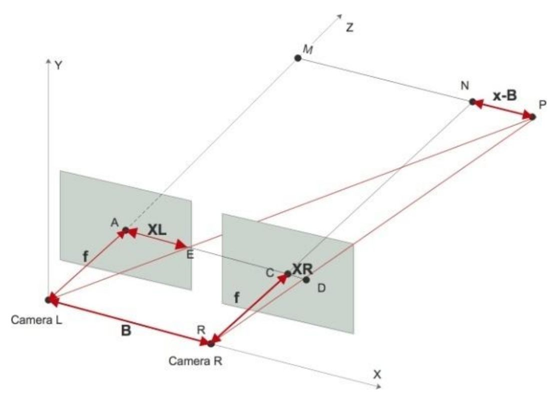


Fig. 8.Triangulation Method to Reproject Disparity Image.

E. Road Surface Fitting

With all the 3-D world coordinates points, we can fit the road surface using the bi-square weighted robust least squares method .By using the least square method all the points are usually regarded as equal quality when fit to a road surface. This includes those pothole points that are below the road surface or those noise points that might influence the accuracy of the fitted road surface. This method used in our road pothole detection system add an additional scale factor (the weight) that help to minimize the outliers' influences during the fitting processes by. All the outliers below the road surface can be detected as pothole regions.

F. Road Pothole Labelling

Firstly we need to label the detected pothole region using the Connected component labeling algorithm. If in case there are more than one road pothole in the region, we number these road potholes with the connected component labeling algorithm. The labeling process consists of 2 passes.

The flowchart of the first pass of judgment is illustrated in Figure 9. We obtain a pixel from the binary image and check whether this pixel is a background pixel. We only label non-background pixel. For non-background pixel, we check whether there is existing label around this pixel. If there is not an existing label around this pixel, create a new label for it. Otherwise copy the existing label if there is only 1 label around this pixel. Copy the smaller label and mark the bigger label as a child label of the smaller label.

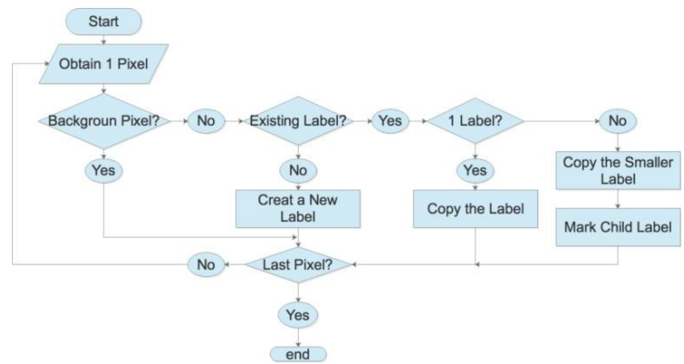


Fig. 9.The First Pass Flowchart.

The flow chart of these condpass of judgment is illustrated in Figure10.We obtain a pixel from the result labeling image of the first pass and check whether it is a child label. We re place it with the parent label if it is a child label.

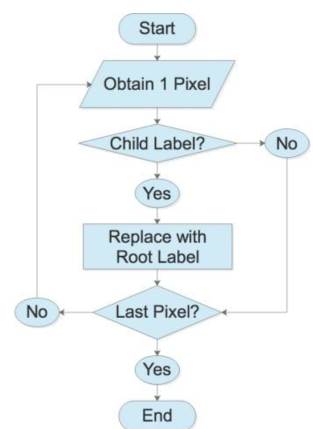


Fig. 10.The Second Pass Flowchart.

IV. Experimental Setup and Results

A. *Experimental Setup*

By using this system, we required to perform two experiments. First, we calibrate the camera which should be done only once unless we change with another pair of stereo cameras. In Glennan519C laboratory the camera calibration experiment is done. We including position and posture by take 20 image pairs of the checkerboard's different poses. The posture of the checkerboard in every image should be as different as possible. Then ,we can employ the experimental setup in real road environment to detect road potholes. We detect a pothole for our experiments in the Case Western Reserve University parking lot 1. We find or detect the pothole by moving two USB cameras mounted on the roller cart to imitate the cameras moving with the car, but at a low speed. The experimental setup for pothole detection is shown in Figure 11. We can done this experiment in serval times under different weather including snowy day and sunny day. Both of these two experiments use the same experimental setup including 2 USB cameras, optical trial , tripodand raspberry Pi 2 modelB. For the software setup, opencv-python3.3 and python 3.6 are required.

In the proposed system, we use the Raspberry Pi2ModelB, which is a single-board computer.

We use to dependent cameras to imitate the stereo camera, and we should make sure the two cameras are mounted at the same height and same horizontal direction using the optical rail and tripod.

B. *Results*

The final road potholes detection result shown in Figure 12 with their geometric information.

Taking a 640×480 image as an example, Figure 13 is the time consumption report for the road pothole detection system.

The single camera calibration using 20 checkerboard images for 2 cameras together takes around $3.52s$. However, wedo not need to calibrate every time when we start to detect road pothole. The camera calibration can be done in advance, and all camera parameters saved locally for later use. Of course, the time consumption for road pothole labeling depends on how many potholes detected. If 0 pothole detected, the time consumption for this part is 0 as well. Therefore, the total time of a road pothole detection is around $5s$, which means if the car drives at $30 miles/hour$, we should detect the road pothole atleast 14 $meters$ in advance.

The above timing consumption depends on image size as well. The larger the image size is; the more pixels need to be processed; the longer it takes. Therefore, we only select the road surface in front of car as region of interest (ROI) to reduce the timing consumption for the proposed road pothole detection system.

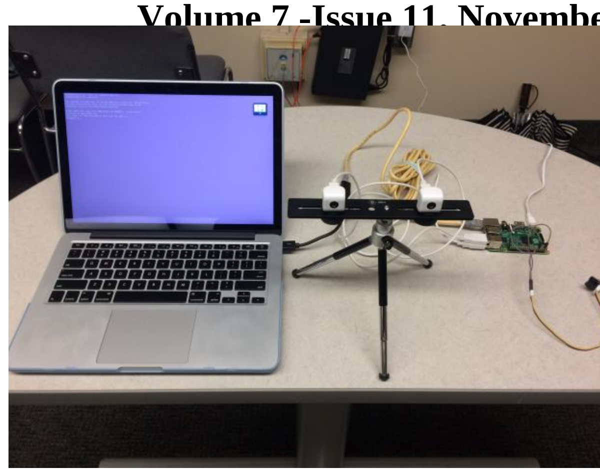


Fig. 11.The Experimental Setup for Pothole Detection.

Fig. 12.Pothole with Geometric Information in CWRU Parking Lot 1.

Category	Calibration	Prepocessing	Disparity Calculation	Surface Fitting	Pothole Detection	Pothole Labelling	Total
Time(seconds)	3.52	0.18	0.17	2.75	1.57	0.26	4.94

Fig. 13.Timing Consumption Report of Proposed System.

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