

Multi-sensor pothole detection and monitoring system

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Summary: A pothole detection and monitoring system is designed and built to enhance maintenance planning by accurately localizing and assessing potholes as potential sources of danger for traffic. This multi-sensor system combines data from several sources. Two infrared cameras generate a depth image, an RGB camera captures visuals processed by AI-based algorithms for depth and segmentation, a radar sensor identifies surface irregularities, and a vibration sensor detects impacts from rough surfaces. By fusing the outputs of all sensors, the system achieves reliable pothole detection across diverse conditions. An integrated RTK GPS system helps to locate the events accurately.

Keywords: pothole detection, road surface observation, bicycle and pedestrian paths, depth imaging, stereo vision, radar analysis, vibration analysis, convolution neural network algorithms

Introduction and Motivation

As reported by the Germany Federal Statistical Office, a number of cyclist fatalities have been attributed to the lack of maintenance of cycling infrastructure [1]. This is largely attributed to the fact that many cities do not prioritize the development of such infrastructure [2]. These circumstances highlight the necessity for a system that can effectively detect and monitor potholes, with the aim of enhancing safety.

The current approach to pothole detection relies on a combination of manual inspections, citizen reports, and automated methods based on stereo vision [3,4], convolutional neural network (CNN) algorithms [5,6], radar sensors [7,8] and vibrations sensors [9,10]. However, each method has its own limitations. For instance, vibration sensors have been observed to generate false positives on stone roads, while stereo vision and CNN algorithms have shown to perform poorly in low-light conditions. Such limitations highlight the necessity for an alternative methodology to enhance the reliability and adaptability of pothole detections. The proposed system overcomes the limitations of a single-sensor system by integrating a multiple-sensor approach, which provides bicycle localization, facilitating road maintenance planning.

Sensor System

The system is mounted on a bicycle at a height of 0.8 m with its sensors facing downward as illustrated in Figure 1. The system comprises three modules connected to a computer via USB: the Intel RealSense D455 depth camera, the Infineon DEMO BGT60UTR11AIP radar

sensor, and the UBLOX ZED-F9R GPS sensor. Two lamps are employed to enhance visibility in low-light conditions.

First, the depth camera computes a disparity map using stereo vision with two infrared cameras and an infrared projector, thereby enhancing depth accuracy on flat surfaces. Additionally, the module incorporates an RGB camera, which serves as an input for CNN algorithms to obtain depth and segmented images. The module Inertial-Measurement-Unit (IMU), comprising accelerometers and gyroscopes, is beneficial for the detection of vibrations. Next, the radar sensor employs the Infineon XENSIV 60 GHz platform, which is effective in distance and speed analysis in low-light conditions. Then, the GPS sensor obtains the longitude, latitude and altitude of the bicycle. This sensor supports both Real-Time-Kinematic (RTK) and dead reckoning. Finally, by integrating the information from all the modules, the system accurately detects and monitors potholes.



Fig. 1. Multi-sensor pothole detection system mounted on a bicycle at a height of 0.8 m

Results

The results of two road deformation scenarios are presented in Figures 2 and 3, which comprise four images each. The top-left quadrant (A) of each figure displays the depth image derived from the disparity map, while the top-right (B) displays the RGB image. In the bottom-left (C), the depth image generated by the "Depth Anything" CNN algorithm [11] is presented. Finally, the bottom-right (D) shows the image segmentation produced by the "Segment Anything" CNN algorithm [12].

Figure 2 illustrates a scenario featuring a road and a sidewalk. The disparity-based and the CNN-derived depth image both demonstrate a clear depth difference between the road and sidewalk. Additionally, the drain is visible in both images, with the CNN algorithm exhibiting superior performance. In the image segmentation, different segments are accurately identified from the RGB image.

Figure 3 illustrates a forested scenario with a bicycle path traversing it. The disparity-based depth image highlights a hole adjacent to the road, as well as leaves and rocks on the path. The CNN-derived depth image, while successful in detecting the leaves and rocks, does not capture the hole with the same accuracy. Conversely, the image segmentation identifies different segments derived from the RGB image.

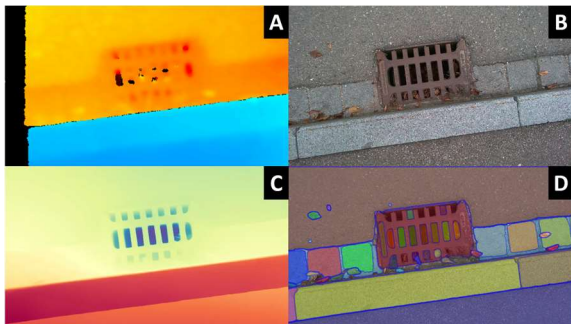


Fig. 2. Road, Sidewalk and drain. (a) Disparity-based depth image, (b) RGB image, (c) CNN-derived depth image [11], (d) Image segmentation [12]

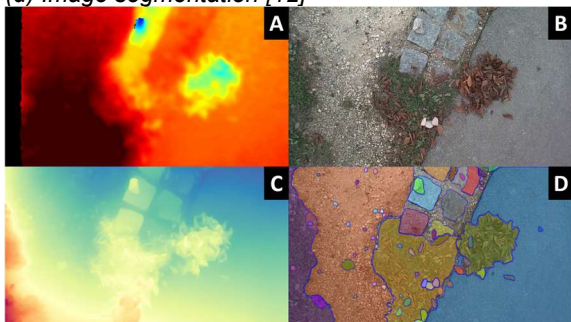


Fig. 3. Bicycle path traversing a forested area. (a) Disparity-based depth image, (b) RGB image, (c) CNN-derived depth image [11], (d) Image segmentation [12]

Conclusions

The study presents a multi-sensor system for the detection and monitoring of potholes on cycling paths, with the objective of enhancing cyclist safety. By analysing depth data from disparity-based methods and CNN-derived algorithms, the system can detect the presence of potholes or deformities with reliability in multiple scenarios. This approach is further enhanced by performing the RGB image segmentation. The results validate the system's capacity to detect surface irregularities.

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