Pothole Detection Using Optical Camera Communication

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***Abstract*—Optical camera communication (OCC) is a potential candidate for the commercial deployment of vehicular communication. Recently, researchers have focused on the development of an OCC-based advanced driver assistance system. In this paper, we have proposed a pothole detection and road banking angle estimation technique from the rear LED shapes of the forwarding vehicle using OCC to ensure safe and comfortable driving. Mathematical approaches, as well as neural network-based methods, have been developed to provide highly accurate results. The proposed system is also applicable to detect stuck vehicles in icy conditions.**

***Index Terms*—optical camera communication (OCC), advanced driver assistance system (ADAS), V2X communication, internet of vehicles (IoV)**

I. Introduction

Every year a significant number of people die and get injured in road accidents worldwide. The distraction of drivers is considered one of the key factors that cause accidents. Drivers can be assisted by providing necessary driving instructions based on the surrounding environments to reduce road accidents. At first, vehicle navigation systems drew attention in the late 1960s in the United States. The related primary goals included reducing highway congestion, increasing fuel efficiency, guiding routes, avoiding vehicle collisions, and collecting tolls electronically [1]. Nowadays, advanced driver-assistance systems are being extensively researched to reduce the number of casualties due to road accidents. Vehicle positioning and vehicle to vehicle (V2V) communication have immense potential to reduce the number of road accidents, making it possible to save the lives of a significant number of people by providing nearby vehicular position information to drivers [2]. In particular, an intelligent transportation system requires precise vehicle positioning to ensure a safe braking distance from surrounding vehicles. The primary focus of the researchers was on radio-frequency (RF) technology over the past decade. The selection of appropriate technology is a challenging task as the vehicular density is high in metropolitan areas. Using RF-based technologies, the system performance is expected to degrade owing to the huge amount of electromagnetic interference. Moreover, regular long-term driving can lead to adverse effects on drivers' health [3].

In addition, the number of connected devices in 5G is growing exponentially, which is supposed to become a more complex scenario in 6G. Therefore, an alternative of RF-based vehicle to everything system is under research as the RF spectrum is overcrowded and highly regulated. Currently, the unregulated massive optical spectrum (10 nm-1 mm) is considered a promising complement of RF technology to support the increasing demand for mobile data. Moreover, high security, immunity from interference, and high energy efficiency have brought unprecedented research attraction in this field [4], [5].

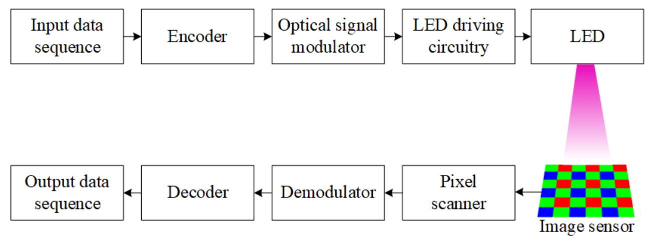

Fig. 1: Block diagram of a basic OCC system.

Recently, the research in optical camera communication (OCC) has attracted significant attention as most modern vehicles are equipped with one or multiple cameras for parking assistance and blind-spot monitoring, these cameras can also be used as receivers whereas the day time running light of vehicles can be modulated flicker freely to transmit data through the optical channel [6]. Therefore, OCC can be commercially deployed in the vehicles without adding too much cost to the existing system. Other key advantages of OCC technology include nearly interference-free communication as each pixel can be processed individually and an unlicensed spectrum that can be used as a complement for the nearly saturated RF spectrum. The basic operation of an OCC system is shown in Fig. 1 [7]. In a V2V communication scenario, the signal-to-noise ratio is high, as the light-emitting-diodes (LEDs) used for lighting have very high luminance. It offers a very strong line-of-sight link set up at a long distance with a low bit error rate. Additionally, the effect of sunlight, a major challenge for other optical wireless communication systems in outdoor environments, can be effectively eliminated. Despite the high-speed switching capability of LEDs, the data rate of OCC systems is predominantly limited by the camera

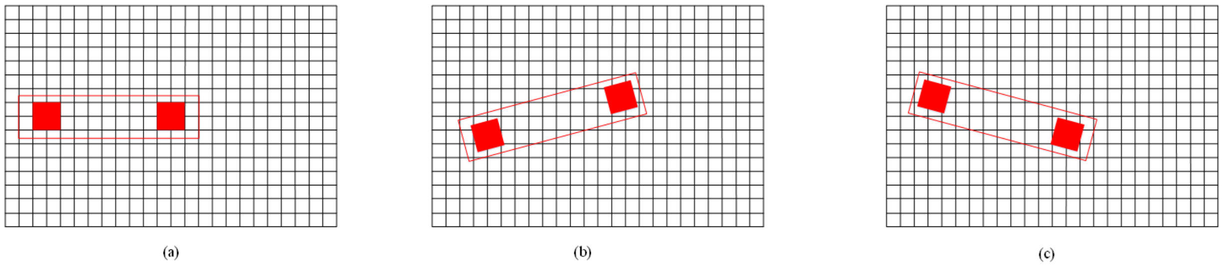

Fig. 2: Alignment of the rear LEDs when the FWV goes over a a) plain surface, b) pothole under the left wheel, and c) pothole under the right wheel.

frame rate. Therefore, the significant advantages of OCC are often overshadowed by its low data rate [4]. Researchers have already proposed a high-speed camera and multiple-input multiple-output technique using an LED array to increase the data rate to one suitable for sensor data monitoring [8], patient monitoring [9], vehicular communication [10], and other low-rate indoor and outdoor applications [11], [12]. OCC can support numerous applications including platooning, emergency brake light detection, collision avoidance, traffic light recognition, and intersection assistance. Inter-distance between vehicles can also be estimated using OCC. Thus,it can be used to maintain a safe distance between vehicles [2], [10], [13]. Information on traffic accidents, road repair works, and traffic flow can be relayed from V2V to ensure safety and comfortable driving. Moreover, the front view of the forwarding vehicle (FWV) can be perceived by the following vehicle (FLV) using video streaming to enable the see-thorough feature [4]. In our previous work, we had developed a road curvature estimation technique from the rear LED shapes of the FWV using OCC to reduce the accidents at the road bendings [2]. In this work, we have designed a system that can measure the angle between the two rear LEDs of a vehicle so that potholes and vehicles stuck in the ice can be detected. Additionally, the road banking angle can also be estimated from the rear LED positions of the FWV.

The remainder of this paper is organized into the following sections. Section II presents the methodology where the overall architecture, dataset preparation, and mathematical approach are described. In the next section, the results are discussed. Then, the conclusion and future work are mentioned in Section IV.

II. Methodology

A. Overall Architecture

The 'x' coordinates of the LEDs vary with the lateral movement of the FWVs, FLVs, or both in the captured image in the FLV's camera receiver keeping the 'y' coordinate of the LEDs the same as shown in Fig. 2(a). If one of the rear wheels runs over a pothole, the vertical coordinates of the rear LEDs of the FWV will no longer remain the same which is shown in Fig. 2(b) and Fig.2(c). The flowchart of pothole detection and measurement using OCC is shown in

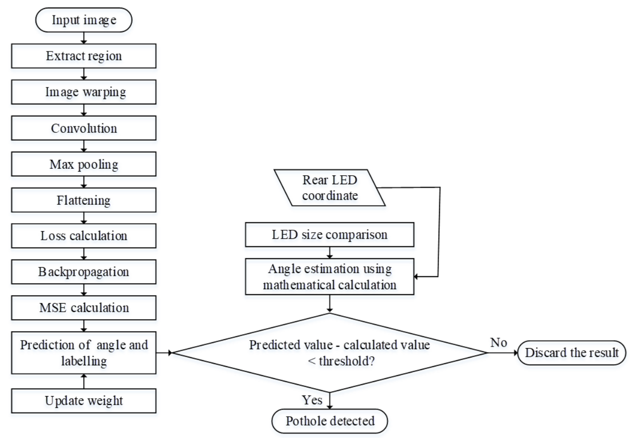

Fig. 3: Flowchart of the pothole detection and road banking angle calculation using OCC.

Fig. 3. The deep learning-based method is more accurate than the mathematical approach. Both methods are compared to provide a more accurate result. If there is any discrepancy between the mathematical method and the neural network (NN)-based method, it is tolerated up to a certain level and the result of the deep learning-based approach is shown as output. However, if the difference is more than the threshold (for instance 5°), that is removed from the calculation. It can be noted that this process doesn't affect the overall system performance. For instance, a 30 frame rate per second (fps) camera captures 30 images in one second and each image will provide one result. Therefore, if a high frame rate camera is used, the number of results obtained in one second will be equal to the frame rate of the camera. As a result, if some of the results are discarded, it will not create any significant performance degradation. The NN-based approach and mathematical approach are described in the following subsections.

B. Dataset Preparation

5,000 images were taken at various angular positions with their associated angles. The dataset had a dimension of $5,000 \times 6$ where the input and output vectors had the dimension of $5,000 \times 5$ and $5,000 \times 1$, respectively. In a real-time

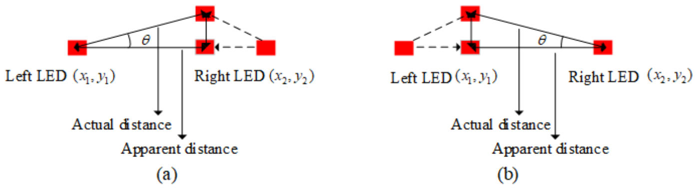

Fig. 4: Hypothetical triangle for calculation of pothole angle when the FWV goes over a pothole under the (a) left wheel and (b) right wheel.

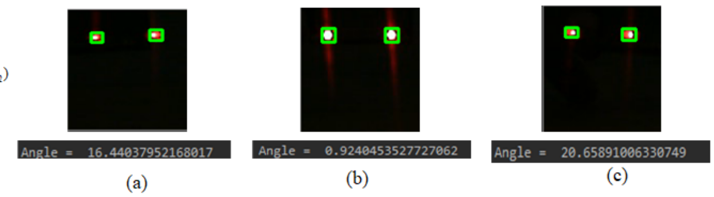

Fig. 5: A demonstration of the estimation of the angle between rear LEDs when the FWV goes over (a) a pothole under the left wheel, (b) pothole free road, and (c) a pothole under the left wheel.

scenario, numerous lights can be present in an image where most of the light sources are unwanted and can be considered as interfering light sources. Again, processing all the pixels of an image is unnecessary and time-consuming. Therefore, a convolutional NN (CNN) including two hidden layers was designed for image classification. The individual rear LED pair of vehicles were warped as individual images and a convolutional filter of 4×4 was used for feature extraction. Then, max-pooling was performed with a 2×2 filter to reduce the image size more. Then, it is flattened so that it can be used as the input of the NN.

C. Mathematical Approach

When the vehicle goes over a pothole or got stuck in ice or there is road banking, the 'y' coordinates of the rear LEDs will be dissimilar. A hypothetical triangle can be formed which is shown in Fig. 4(a) and Fig. 4(b). The angle between the rear LEDs can be calculated from these triangles which require prior knowledge of the actual distance between the rear LEDs. This information is transmitted from the rear LEDs of the FWV to other FLVs using OCC. And, to calculate the apparent distance between the rear LEDs, the distance for each pixel is calculated as the distance between the rear LEDs is known. Then, the angle can be calculated using the cosine function as follows

$$Angle\ between\ LEDs,\ \theta = \cos^{-1}\left(\frac{base}{hypotenuse}\right), \tag{1}$$

$$\theta = \cos^{-1}\left(\frac{apparent\ dist.\ between\ rear\ LEDs}{actual\ distance\ between\ rear\ LEDs}\right). \tag{2}$$

TABLE I: Implementation parameters.

	Parameter	Value
Camera	Image resolution	1080×1920
	Camera frame rate	30 fps
	Exposure time	2.5 ms
Backlight prototype	Distance between two LEDs	10 cm
	LED size	3 mm red LED
	Maximum distance	50 m

III. Result and Discussion

The performance of our proposed scheme was verified experimentally. On the transmitter side, there were two parts such as the vehicle taillight prototype and an Arduino UNO to operate the LEDs. On the receiver side, a rolling shutter (RS) camera was used to capture the images and Python 3.7 was used for LED detection and the rest of the processing. After LED detection, data was retrieved from the brightness of the stripes created on the image sensor due to the RS effect. And, the angle between LEDs was estimated from the rear LED coordinates of the FWV.

To evaluate the performance of our suggested system economically, we built a vehicle taillight prototype. The LEDs were connected with an Arduino UNO and DC power was supplied for the operation. It was implemented in an indoor environment where the sunlight and light from artificial sources were the interfering lights. Table I contains the implementation parameters. The pair was tilted to the left and right, and the results were recorded. The results were compared with the actual values to assess the performance of the proposed method. The threshold was set to 5° so that any discrepancy higher than this limit could be discarded. It was observed that the deviations remained below the predefined limit. A sample of the implementation results is shown in Fig. 5(a), Fig. 5(b), and Fig. 5(c).

IV. Conclusion and Future Work

This work adds a new feature in the OCC-based advanced driver assistance system (ADAS). The stuck vehicles in the ice, potholes, and road banking angles can be detected or estimated from the rear LED shapes of the FWVs using our proposed technique. Our proposed method is expected to assist the drivers even in adverse weather conditions, such as rainy, snowy, and foggy. Therefore, pothole detection can play a key role in safe and comfortable driving making OCC a promising candidate for vehicular communication because it not only provides communication but also ADAS features. The more the features will be developed, the higher the chance of commercial deployment of OCC-based ADAS. Therefore, we will conduct our future research to connect the vehicles at roundabouts using OCC technology.

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