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광학 카메라 통신시스템 기반 야간 LED 후미등 검출 방법

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Nighttime LED Taillight Detection Method with Optical Camera Communication System

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요 약

차량용 광학 카메라 통신 시스템에서는 LED 테일라이트 이미지에서 송신기로 데이터를 얻습니다. 이 데이터는 차량용 고속 카메라에 수신기로 캡처됩니다. 이 기술에는 첨단 운송 시스템을 제공할 수 있는 몇 가지 잠재력이 있습니다. 많은 관련 주제 중 광학 카메라 통신이 최근 몇 년 동안 이미지 처리 기법의 발달로 인해 차량 위치 지정 애플리케이션의 전통적인 방법을 대체할 것으로 예상됩니다. 처음에 본 연구에서는 광학 카메라 통신 기반 차량 포지셔닝 프로세스를 소개합니다. 둘째, 영상에서 LED 테일라이트를 검출하는 방법이 제안됩니다. 이를 통해 감지된 LED 테일라이트의 이미지 위치를 사용하여 프론트 차량의 위치를 추정할 수 있습니다. 마지막으로, 실제 상황에서 제안된 방법의 성능을 야간 실외 환경에서 캡처한 이미지의 검출 결과에 따라 평가합니다.

Key Words : LED, taillight, optical, camera, communication, positioning, detection

ABSTRACT

In a vehicular Optical Camera Communication system, the data are obtained from the image of LED taillight as the transmitter, which is captured by the on-vehicle high-speed camera as the receiver. This technology has several potentials that can be provided for delivering advanced transport system. Among many related topics, Optical Camera Communication is expected to replace traditional methods in vehicle positioning application due to the development of image processing techniques in recent years. Initially, this study introduces an Optical Camera Communication-based vehicle positioning process. Secondly, a method of detecting LED taillight in the image is proposed. This allows the position of front vehicles to be estimated using the image position of the detected LED taillights. Finally, the performance of the proposed method in real-world situations is evaluated according to the detection result on an image captured in a nighttime outdoor environment.

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Ⅰ. Introduction

Transportation is always an essential factor in human lives since it plays a significant role to develop the civilization of mankind. Therefore nowadays, more and more researches are proposed which aimed at improving the limitations of traditional transportation and constructing an Intelligent Transport System (ITS) - an ideal application for the future of a better, safer traffic network. Among several potential communication technologies that can be utilized for the ITS, optical camera communication (OCC)[1-3] is arguably rising as one of the most promising candidates due to the rapid development of the Light-Emitting-Diode (LED) and the CMOS camera. Based on LED characteristics, OCC is considered suitable for short-to-middle-range communication on the traffic road, including vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. However, the capability of OCC has still not been fully exploited yet. For instance, the research topics around OCC which relevant to V2V positioning are still at the beginning phase. Refer to previous studies, many drawbacks that affect the performance of the existing positioning technologies such as TDOA, LIDAR... have been observed[4,5], whereas OCC can be considered as one alternative solution owing to its advantages as follows. First, we can exploit the existing hardware, including vehicular lighting (headlight, taillight, daytime running light...) and on-vehicle high-speed cameras. Second, V2V communication can help in improving the positioning accuracy when the vehicle transfer information to each other. Third, the image processing tasks are becoming much easier the recent days, thanks to the continuous improvement of the hardware and software technologies.

Some recent studies have already mentioned about utilizing OCC for V2V positioning[5-8]. Specifically, they use two cameras to determine the world coordinate of the LED taillights by processing the images which capture these taillights. Consequently, the world coordinate of the front vehicle which contains these taillights will be estimated. However, as all of these papers were based on simulation experiments, they have not mentioned about how to detect the LED taillights from the image in the real situation, which is potentially challenging. Therefore, in this study, we propose a lightweight detection method to determine the region and pixel coordinate of every LED taillight that appeared in the image, which will be used for the V2V positioning target. Besides, we experiment in the urban traffic at nighttime to evaluate the performance of the proposed method on the captured images.

The remaining part of this paper is structured as follows. In Section II, the OCC-based vehicle positioning process is briefly explained, whereas the proposed LED taillight detection method is described in Section III. In Section IV, the proposed method is evaluated by analyzing the results of an outdoor experiment. Finally, the conclusion is drawn in Section V.

Ⅱ. OCC-based vehicle positioning process

In this section, the entire scheme of the OCC-based vehicle positioning process, which

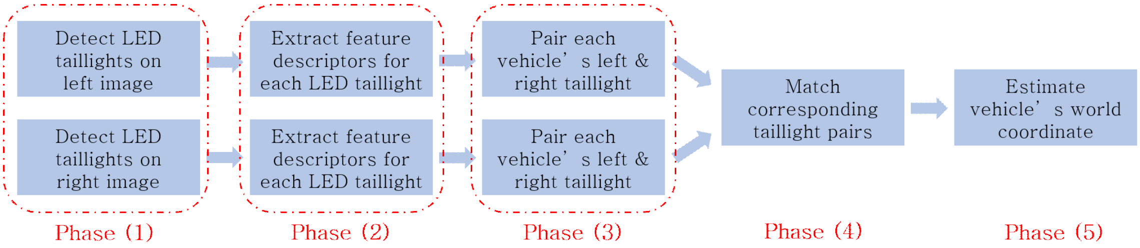

Fig. 1. An OCC-based vehicle positioning process.

includes five phases, is presented in Fig. 1. In Phase (1), on each left and right image, the proposed method is applied to determine the region and pixel coordinate of every appeared LED taillight. In Phase (2), the feature descriptor can be extracted from the obtained region using feature description algorithms such as SURF[9] or FAST[10]. Based on the feature descriptor and the assumption that taillight pairs must be symmetrical, each pair of detected taillights that belong to the same vehicle are associated in Phase (3). Phase (4) is to ascertain which taillight pair of the left image corresponds to which taillight pair of the right image. Finally, in Phase (5), the world coordinate of each front vehicle is estimated using the stereo triangulation approach[11].

Ⅲ. Proposed method

A proposed method for LED taillight detection includes four sequential steps as illustrated in Fig. 2. This method aims to obtain the image position of every LED taillight from the image while preserving the shape and color features for the matching step. The image position of each LED taillight is determined as the centroid of its corresponding minimum bounding rectangle. The details of each step will be described in the following subsections.

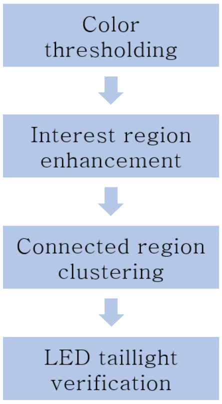

Fig. 2. A proposed LED taillight detection method.

3.1 Color thresholding

In nighttime conditions, various shapes of vehicle taillights are observed as white bright regions with surrounding red. Specifically, there is no common standard for the shape of vehicle taillights. Different vehicle types and different brands may have different taillight shapes. However, we can base on the global regulation of the taillight color and brightness to find out the candidate taillight pixels from the image. In [12], the authors have examined a large database of the tail and brake light images to observe the color distribution of taillight pixels and derive the threshold limit. At first, the real image is converted into an HSV color space that is more adaptable to the regulation color region. Then the derived threshold limits on H, S, and V components are applied so that the red pixels surrounding each candidate taillight will be preserved, while the others are filtered out as black pixels, as illustrated in Fig. 3.

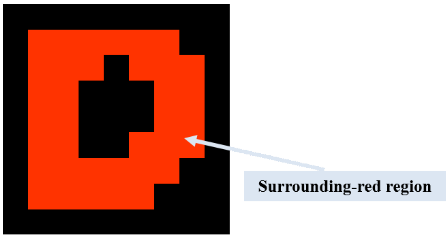

Fig. 3. Thresholding result.

3.2 Interest region enhancement

After the first step, the obtained result is discrete interesting segments. Therefore, the morphological close transformation[13] is used to enhance the candidate taillight regions by merging adjacent candidate taillight segments and filling the pixels inside the surrounding red of each candidate

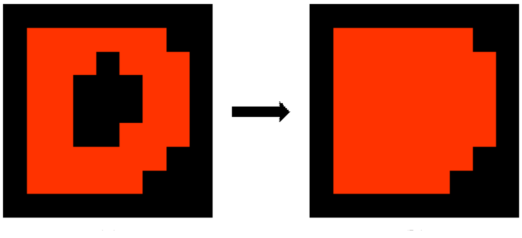
(a) (b)

Fig. 4. Morphological close transformation: (a) Input; (b) Output.

taillight. The structuring element using for the transformation is empirically chosen as the square disk with size 12x12. The result after enhancing is briefly described in Fig. 4.

3.3 Connected region clustering

Although the segmented taillight regions have already been enhanced, they are not labeled yet. And the position of each taillight still needs to be determined. Denote north and west neighbor as the adjacent point in the north and west of the current pixel, respectively. In the third step, the derivative of the connected-component analysis algorithm[14] is utilized to cluster connected candidate taillight pixels into specified taillight regions. This connected region clustering algorithm is described in Fig. 5.

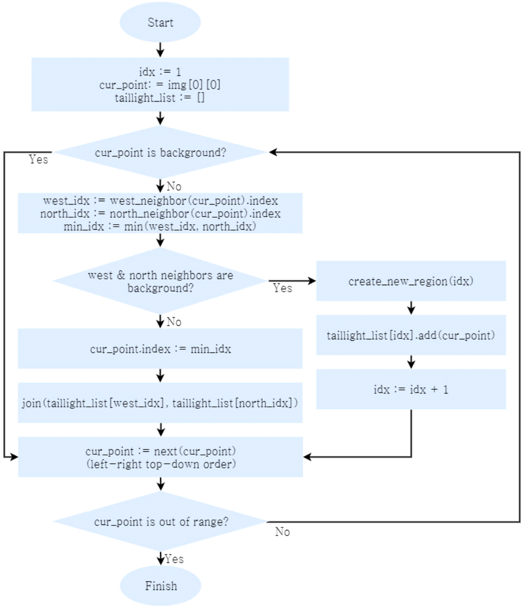

Fig. 5. A proposed connected region clustering algorithm.

3.4 LED taillight verification

After labeling taillight regions, some outliers likely remain in the output image. When applying some rules we can remove out a part of them. For instance, the brake lamp region may be detected based on the ratio between the region width and height. The region with the tiny area, or has a vertical position too higher than the road can also be eliminated.

Ⅳ. Experiment

We set up an experiment on the urban traffic road in the nighttime. The camera is placed on the tripod with the height is 130 cm, as presented in Fig. 6. The camera model we use is a Sony Cybershot DSC-RX100 with a CMOS image sensor. The resolution is set as 1920x1080 while the exposure time, ISO, f-Number, and focal length are respectively configured as 1/200 (s), 800, 5.6, and 35 (mm).

We capture 511 images and running the proposed method on them to generate 511 test sets. Each test set consists of the detection result image and the corresponding ground truth image as illustrated in Fig. 7. The taillight regions are highlighted in green rectangles. We will compare the number of green rectangles in result images with that in ground-truth images. Denote the number of the correctly detected taillight is TP, the number of the falsely detected taillight is FP, and the number of the missed taillight is FN. We use the precision and recall to evaluate

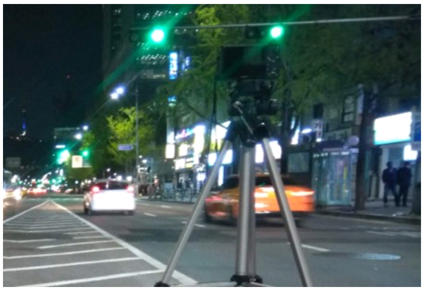

Fig. 6. Experimental setup.

(a) (b)

Fig. 7. Some test samples: (a) Ground truth; (b) Detection result.

the performance of the proposed method on 511 test sets. The precision and recall rates are calculated using TP, FP, and FN as below:

$$precision = \frac{TP}{TP + FP}$$

$$recall = \frac{TP}{TP + FN}$$

Finally, we obtain the experimental results as follows:

From the obtained results in Table 1, we can observe that the recall is high since the proposed method can detect the candidate taillight region from the images well. However, it comes along with the high number of falsely detected taillights, which makes the precision is not good. Although the redundant regions can be eliminated in the further phases of the OCC process, it will lead to an increase in the computational complexity of the V2V positioning application. Therefore, this is the main challenge that we have to address in the future works to make the taillight detection method to become more efficient in real situations.

Table 1. Experimental results.

TP	FP	FN	precision (%)	recall (%)
2356	171	104	93.23	95.77

V. Conclusion

In this study, we explore one application for OCC technology in a transportation system that is V2V positioning. To utilize this application for the urban traffic at nighttime conditions, we propose a lightweight LED taillight detection that aims to locate the region and determine the image position of all LED taillights from the captured image. The obtained results from an experiment in nighttime urban traffic show that the proposed method can detect the candidate taillights from the image well, but it still cannot eliminate all the noises that are not actual taillights. Therefore, future work will aim to improve the performance of the detection algorithm along with providing an efficient framework for the entire OCC-based positioning process.

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