Test Results for V2V and V2I Optical Camera Communications

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***Abstract*—Autonomous vehicles require the integration of multiple communication systems. This paper presents test results of vehicle-to-vehicle (V2V) and vehicle-to-infra (V2I) optical camera communications (OCC). The flicker-free light emitting diode (LED) light sources, providing illumination and data transmission simultaneously, and a high speed camera are used as transmitters and a receiver in the OCC link, respectively. Test results showed that vehicle information sent by tail lamps of a running car ahead and absolute location data sent by streetlights were successfully received at a vehicle's camera via the OCC link.**

Keywords–Optical camera communications (OCC); vehicle-to-vehicle (V2V); vehicle-to-infra (V2I).

I. Introduction

Recently, many people demonstrate great interests in self-driving technology and car makers move toward offering fully autonomous vehicles. Although recent vehicles are equipped with cameras, sensors, and software essential for driving assistance, the advanced level of self-driving requires the functionality of V2V and V2I communication [1]. The future self-driving cars will talk to each other and also talk to any road-side infrastructure equipped with dedicated short-range communications (DSRC) and wireless access in vehicular environment (WAVE) devices [2][3].

There exist some issues concerning the vehicle communication reliability of DSRC and WAVE devices because they use radio frequency (RF) bands, which are vulnerable to multipath fading and channel congestion. This issue is significant when data transmission of road/vehicle safety messaging and vehicle safety control is required. Therefore, autonomous vehicles require the integration of information transmitted via multiple communication mediums.

With the widespread use of LED lights, optical camera communications (OCC) technology [4][5] has gained interests in a variety of fields. An OCC system is a new trend of optical communication using a camera receiver at visible light spectrum. As a back-up system to RF based vehicle communications, OCC technology can be applied to V2V and V2I communication for self-driving vehicles. Because the implementation of an OCC system is based on pre-installed LED lamps and cameras, an OCC system for vehicle communication requirea no substantial additional costs. Along with the advantages of OCC, several researches related to wireless communication in smart traffic systems based on OCC have been conducted recently [6][7].

This paper presents test results of flicker-free OCC for V2V and V2I communications. The flicker-free light sources of car tail lamps and streetlights were used as data transmitters. OCC data can be received by a high speed camera via the OCC link. Test results showed that reliable V2V/V2I communications were provided using the OCC technology.

The remainder of this paper is organized as follows. Section II outlines OCC data communication process. Section III shows test results of OCC based V2V and V2I communications and Section IV reports the discussion.

II. Data communication process

This section explains the process of data communications via the OCC link. LED light sources, such as car tail lamps and streetlights, offer both communication and illumination performance. Because the human eye cannot perceive the light pulses blinking at 200 Hz or higher frequency, a manchester encoding method with a flickering rate of greater than or equal to 200 Hz was used. We set a data frame consisting of 8 bits of synchronization data and 16 bits of information data.

At a receiver-side, a high speed camera captures images with LED light sources containing OCC data and other light noises. To extract the image pixel regions containing OCC data, differential images were obtained and cumulated. An image binarization process was then performed using an appropriate intensity thresholds. To remove the additional noise induced by a camera equipped in a moving vehicle, a morphology erosion scheme was used. Then, region of interests (ROIs) containing OCC data were obtained and symbolic label were added to every ROIs. Because we set the same level of the camera sampling rate and LED flickering rate, a camera captures successive images containing "On" and "OFF" patterns of OCC data. By analyzing the intensity of ROIs in successive images, it is possible to obtain synchronization and information bits.

III. Test results and discussion

In this section we show test results of what we achieved during OCC field tests. For the OCC data transmitter, LED light sources controlled by an AVR microcontroller (ATmega128) were used. As a receiver, a high speed camera (FL3-U3-20E4C-C) with global shutter was used. In subsection III-A, we illustrate the test process and results of V2V OCC. Subsection III-B shows the results of V2I OCC and performance of vehicle location estimation.

A. V2V optical camera communication

In a V2V OCC scenario, LED tail lamps of a running car ahead (sedan) transmit data containing the car brake information (No brake, brake level 1, 2, 3) and the distance between tail lamps. Note that distance between tail lamps can be used for vehicle width estimation, the distance estimation from the car ahead and lane keeping assistance. As an OCC receiver, a high speed camera was equipped in the following

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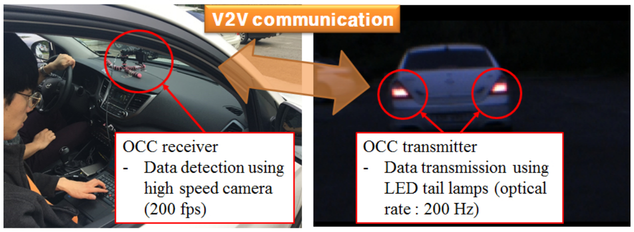

Figure 1. V2V communication scenario

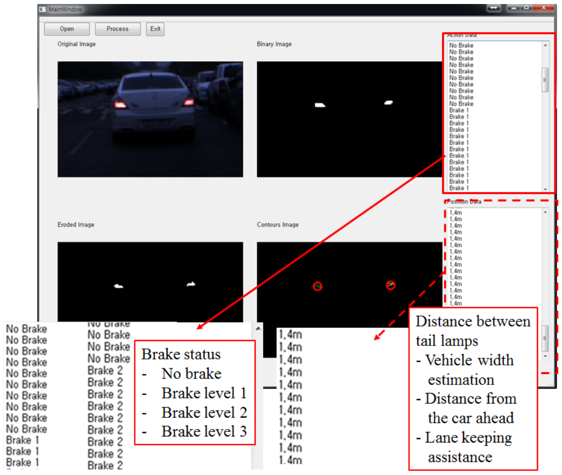

Figure 2. V2V OCC data acquisition

SUV car. As shown in Fig. 2, the camera frame rate and LED flicker rate were set to 200 Hz. The vehicles run within a speed of 40 km/hr. Fig. 3 shows that OCC data including the car brake information and the distance between tail lamps were received successfully even in a moving vehicle.

B. V2I optical camera communication

In a V2I scenario, we consider 6 LED streetlights transmitting their absolute 3D location information. By receiving these information using a high speed camera, the location of a moving vehicle can be estimated. As shown in Fig. 4, the camera frame rate and LED flicker rate were set to 250 Hz. It can be seen from Fig. 5 that the location estimation error lies within a range of $1m$. This means that an OCC system can provide lane-level services for self-driving cars. When the distance from the closest LED was approximately $27.5m$, a change point on the graph was observed due to the change in the number of total observed LEDs sending OCC data.

C. Discussion

Test results of V2V OCC scenario proved that the information from the running car ahead can be transmitted using LED tail lamps and enhance the car safety aspect of self-driving vehicles. In the results of V2I OCC case, absolute location information was transmitted by LED streetlights and captured images containing OCC data provided the estimated vehicle location, with the location estimation error less than $1m$.

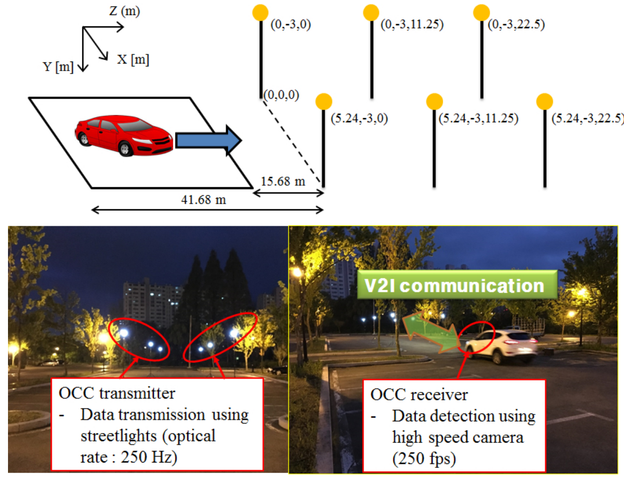

Figure 3. V2I communication scenario

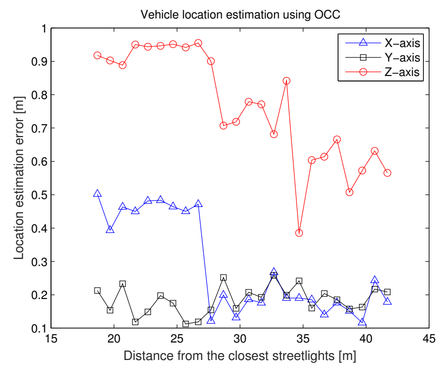

Figure 4. Location estimation error using the received V2I OCC data

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