Feasibility of V2X optical camera communications for road safety applications

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***Abstract*— With the increasing use of cameras and LEDs, interest in optical camera communications (OCC)-based V2X technology is increasing. Using the cameras and LEDs installed in existing vehicle and roadside infrastructures for V2X communications, vehicles on the road can exchange information at a small additional cost. This paper discusses the feasibility of using OCC technology for V2X communications through actual experimental results. For this, we describe actual experiments using OCC in several V2V and V2I experimental environments. Experimental results show that OCC-based V2X communication technology can cooperate with other V2X communication methods in the future to provide safer driving.**

Keywords— Optical camera communications, V2X, LED, roadside infrastructure.

I. Introduction

In the past decade, Vehicle-to-Everything (V2X) communications have become an active research topic for both academia and industry. If a vehicle have the ability to exchange information directly with neighboring vehicles and road infrastructures, many new driving safety and infotainment applications could be provided to drivers and passengers. Dedicated Short Range Communication (DSRC) and wireless access in vehicular environments (WAVE) are often considered the most promising RF–based technology to be used for the V2X applications in both research and industry. [1] They are specifically designed to operate in highly mobile environment and dynamic scenario.

Visible light communication (VLC) uses visible light signals to transmit digital information in free space. [2] Optical camera communication (OCC) is a subset of VLC, where LEDs are used as light sources and camera sensors are used as receivers. [3] Many commercial vehicles already use LEDs such as tail lamps, daytime running lamps (DRLs), direction indicators, headlights, etc. Therefore, OCC for vehicles has emerged as a cost-effective approach to implement V2X communication, as the main components for data exchange already exist in today's vehicles. [4] Using multiple sensors and received data, the transmit data are processed to generate recommendations for driving dedicated to a particular or specific group of drivers and sent wirelessly to the vehicle and road side infrastructures. This data contain events such as the speed of the vehicle, road construction, traffic jam, approach to an emergency vehicle, etc.

Vehicle safety applications require high reliability and low latency. However, RF-based wireless cooperation between vehicles is a challenging problem due to the possibility of channel congestion and a large amount of dynamic data exchange. Therefore, the use of OCC for V2X could be very helpful for the vehicle connection application so that a dropped connection is less likely to happen in the middle of an active transmission. However, a much less number of prototypes have been realized and tested in various environments, showing promising features of OCC-based V2X technologies.

In this paper, we introduce several OCC-based V2X experiments to confirm the feasibility of its use in safety driving technology. A commercial camera mounted on a vehicle is used to capture images of the surrounding while the vehicle was driven on the real road. The captured images are processed to extract visible light data from the LED lamps of other vehicles and road infrastructures in the images. For confirming the feasibility of this system, many experiments have been conducted under real driving conditions. The test results showed that use of OCC technology in future V2X enables more secure and stable autonomous navigation.

II. Vehicle to Vehicle (V2V) Communications

A. *Mirrorless cars applications*

With the interests in new autonomous vehicles, new laws and regulations have allowed automakers to replace their existing side mirrors with rear side view cameras and monitors. [5] In the mirrorless car with this system, the rear and side environment of the vehicle can be seen through the display device. Note that the rear side view using the camera is much wider than that of the conventional side mirror, resulting in elimination of blind spots. Mirrorless vehicles with this system can provide safe driving because they are more sensitive to potential threats or warnings based on camera monitoring systems. In addition, cameras are noticeably smaller than common side view mirrors and these mirrorless cars can provide clean external aerodynamics thereby offering a high potential to achieve improvement of effective fuel use for driving.

In [6], Kim et al. addressed the OCC system for V2V communications based on mirrorless cars. As shown in Fig. 1, The flicker-free light sources of DRL LED light sources were used to convey vehicle's action and vehicle type data to front cars. OCC data can be received by a camera located on the side of the front car via the wireless OCC link. Based on this, it is possible to prevent accidents by informing the front vehicle ahead of time when the rear vehicle overtakes or drives drowsy. In this study, experiments on OCC-based

V2V communications using 4 types of vehicle action schedule, i.e. running, overtaking, cutting in, and caution. The experiments were carried out on a sunny day during daytime and nighttime. Vehicles run in a real-world road at approximately 40 km/h. The camera frame rate and LED flicker rate were set to 200 fps and 200 Hz, respectively. Image pixel size is set to 320 x 240. In Fig. 2 and 3, the left side shows the rear side vehicle observed from the front vehicle and the right side shows the simulator for analyzing the OCC data. Experimental results show that optical V2V communications for mirrorless cars can transmit OCC data successfully and can be an alternative technology for safety driving.

Figure 1 Transceivers in mirrorless car connection

Figure 2 Overtaking scenario in daytime

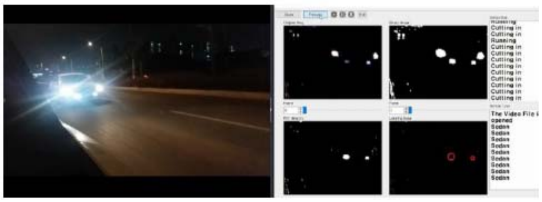

Figure 3 Cutting in scenario in nighttime

B. Autonomous platooning applications

The vehicle platooning technology can significantly increase highway capacity and reduce fuel consumption. It is no wonder that vehicle platooning has been the popular focus of vehicle research for decades. Particular focuses are placed on cooperative acceleration, braking of the vehicle, and steering wheeling control.

The autonomous platooning technology uses multiple sensing information such as radar and camera, and V2V communication information, so that multiple vehicles can maintain a proper distance and control the steering. Although it is possible to maintain the distance of the rear vehicle via the radar sensor, it is important to know the moving route of the front vehicle in order to control the steering. In order to control the steering of the rear vehicle according to the movement path of the front vehicle, an OCC technology that transmits data using a high-speed modulation function of the LED light source and receives data through the camera is needed.

In the current autonomous platooning technology, the rear vehicle must recognize the lane for steering control. However, there is a possibility that lane recognition cannot be realized due to bad weather conditions such as heavy snow, rain, and road aging, and thus, a technique capable of coping with sudden changes in the route of the leading vehicle due to obstacles on the road is needed. In [7], the experimental result of steering control based on OCC technology in autonomous platooning is presented. Despite the sudden change in the direction of the preceding vehicle due to the bad road surface, steering control was performed correctly using both the lane recognition and center point information of the tail light of the preceding vehicle. If the optical camera communication technology is applied to the autonomous platooning technology, it is possible to know the driving information and moving path of the forward vehicle effectively by utilizing the taillight of the front vehicle and the camera of the rear vehicle. The test results from the V2V OCC scenario proved that the information from the driving car was transmitted using the LED taillight and can enhance the vehicle safety aspect of autonomous vehicles.

Figure 4 Steering control in autonomous platooning

III. Vehicle to Infrastructure(V2I) Communications

A. Road side information

Recently, lighting infrastructures on the road are changing to LED lighting. The characteristics of LED lighting are spreading to various fields because of its energy efficiency, long life expectancy, low maintenance cost. In the transport sector, LEDs have started to be used for traffic lights, street lighting or signage. Since LEDs and cameras are already used for vehicles and roadside, it is easy to apply OCC to intelligent transportation systems (ITS).

In ITS, it is necessary to use a camera to recognize road signs by driver. However, it is often difficult to recognize signboard information due to the ambient light noise. Furthermore, the existing image processing technology cannot recognize the road signs due to the roadside tree, distracting infrastructure in front of the signboard, and damaged signboard. In addition, Roads often change in a crowded city, so road signs often need to be replaced. If we can provide information about road signs using LED lights which are already constructed on the road, we expect that it will help to realize ITS without having to construct additional infrastructure. Simply modifying the roadside information stored in the web server rather than replacing the road signs can reduce the environmental pollution caused by aluminum processing. The concept of replacing road signs using web server and OCC is shown in Fig. 5. By combining OCC and Web server-client for V2I communications, real-time road information can be transmitted from LED light sources such as traffic lights and street lights without physical road signs, providing smooth traffic conditions and help prevent accidents.

In [8], an OCC-based V2I technology to obtain road sign information based on road LED lighting infrastructure was addressed. As a result of experiments on actual roads, it was confirmed that the visible light data through the image sensor attached to the vehicle was received and the corresponding signboard image from the on-board processor or web server was presented through GUI screen. Even though the speed of the moving vehicle and the brightness of the surroundings are changed, the time required from the recognition of the LED light source to the image processing is short, and the desired information can be quickly presented. As shown in Fig. 6, it can be applied to intelligent navigation by providing multiple road sign information from one light source and the location of the light source on the map.

The system consists of a broadcast unit represented by a LED-based traffic light and a camera based receiver. The transmitter module was developed based on a commercial LED-based traffic light in order to investigate up until what point any traffic light can become a data broadcast unit with little modifications and at the lower cost.

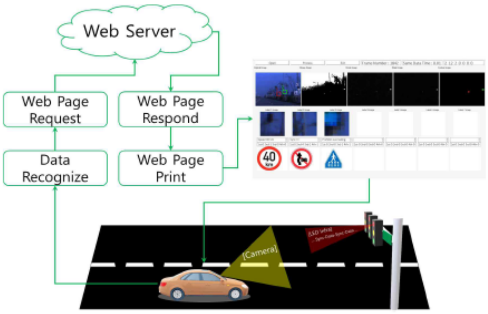

Figure 5 Concept of replacing road signs using web server and OCC

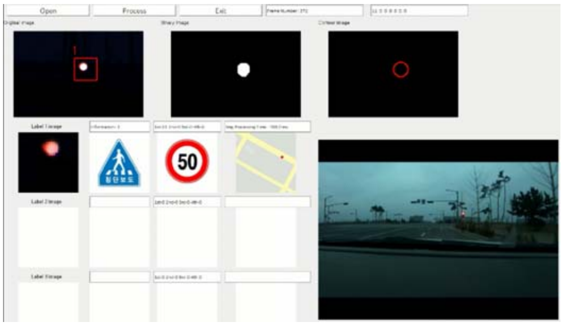

Figure 6 Multiple road sign information from one light source

B. Vehicle location estimation

Although GPS technology for location positioning system has been widely used, it is difficult to be used in ITS due to the large positioning error and limited area for receiving radio signals. Because GPS uses radio waves, measurement errors often occur up to tens of meters due to multipath or radio interference, making it difficult to use in intelligent traffic systems that predict and control traffic flow. In addition, it is impossible for the GPS-based positioning system to measure the position in an environment where radio waves cannot pass through a tunnel or an underground road.

In the V2I environment, LED infrastructure lighting installed on the road has an absolute coordinate, and this absolute coordinate can be transmitted through the visible light-modulated signal, thereby suggesting a method of measuring the position of the vehicle. Since the absolute coordinates of the infrastructure illumination are used directly, the positioning error is significantly reduced compared with the GPS technology, and positioning using the location and orientation estimation is possible even in a region where reception of GPS signals is difficult, such as a tunnel or underground. The proposed method utilizes camera images that are easily mounted on vehicles, so the implementation complexity is low.

When the image containing the LED light source is obtained, the 3D location data included in the visible light data transmitted from the LED light source together with the 2D location of the LED light source on the image plane can be obtained. Based on this, the position of the current camera sensor in the 3D space, that is, the position of the vehicle in a real world, can be estimated. To convert between 3D space and 2D images, a collinearity condition can be used. After detecting the LED signal area on the image plane, the center point position of the image sensor in three dimensions can be obtained by using the 2D coordinate value on the image plane where the LED signal is located.

In [9], a method of estimating the position of a vehicle by using 3D coordinate points sent from multiple light sources was proposed. As can be seen in Fig. 7, six LED street lights that transmit absolute 3D position information and a vehicle traveling in the direction of light sources were considered. By receiving the visible light information using a camera, it is possible to estimate the 3D position of the moving vehicle. The frame rate of the camera and the flicker rate of the LED are set to 250 Hz. From Fig. 8, it can be seen that the position estimation error is in the range of 1m. This means that the OCC-based V2I system can provide lane level navigation services to vehicles.

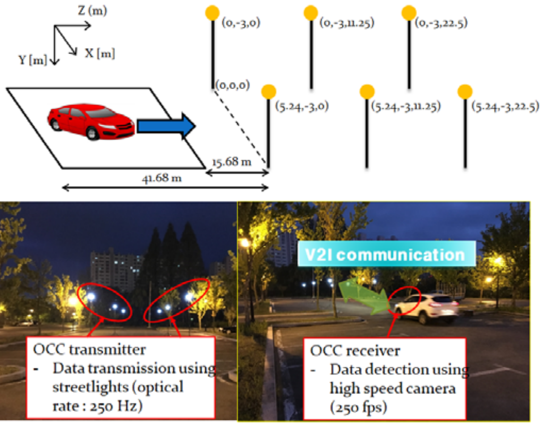

Figure 7 Experimental environment of OCC-based vehicle positioning method

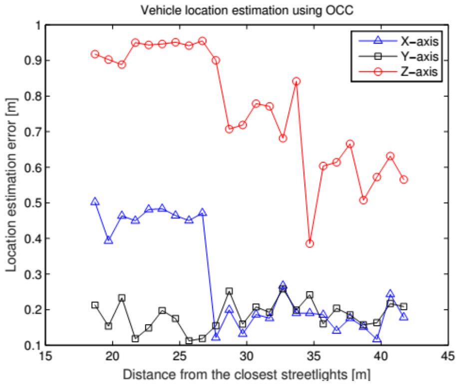

Figure 8 Vehicle position error according to each axis

IV. Conclusions

In this paper, we present experimental results showing that OCC technology can be applied to V2X. LED and camera-based communication technologies already installed in vehicle and road infrastructure have the potential to complement existing RF and GPS-based V2X. OCC technology can be applied to V2V to provide safe driving information between mirrorless vehicles or to improve the performance of autonomous communities. When applied to V2I, information on the road can be transmitted to the vehicle and precise vehicle positioning is possible. The use of OCC technology in future V2Xs enables more secure autonomous navigation.

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