Development and Control of Wireless Mobile Surveillance Camera System with Omni Directional Lens

Jungyu Kim[1], Taesung Kim[2] and Hyunsoo Lee[3†]

[1]School of Industrial Engineering, Kumoh National Institute of Technology, Gumi, Korea
(Tel : +82-54-478-7681; E-mail: rlawnsrb3@kumoh.ac.kr)
[2]School of Industrial Engineering, Kumoh National Institute of Technology, Gumi, Korea
(Tel : +82-54-478-7659; E-mail: tkim@kumoh.ac.kr)
[3]School of Industrial Engineering, Kumoh National Institute of Technology, Gumi, Korea
(Tel : +82-54-478-7661; E-mail: hsl@kumoh.ac.kr)

Abstract: This research suggests a mobile surveillance camera system which can be used as a surveillance and a black box system in motorbikes. The camera system has an omnidirectional lens for recording full-directional situations with the consideration of these transportations. The recorded image frame is unwrapped using the provided image processing technique with the considerations of processing quality and time. The control of the camera system is executed using the secured control message transfer and IEEE 802.11 based wireless communication protocol. In order to prove the effectiveness of the provided system and its control, the prototype and an Android based control app are provided.

Keywords: Wireless control system, omnidirectional lens, embedded system control, unwrapping algorithm.

1. INTRODUCTION

Surveillance camera systems have been an essential module in various transportations such as sedans, trucks, ships and airplanes. These camera modules have several usages; taking motion frames from a car accident, guiding parking routes or checking nearby pedestrians or other transportations. The representative application using these camera modules is a black box. Fig.1 shows a conceptual car black box system using several camera modules.

Fig.1 Conceptual car black box system using several camera modules.

Even though there are many benefits from the installation of the camera module, its usage is limited in the fact that the image taken from a camera module is obtained only within the limited field of view (FOV) of the lens. As a common camera has a rectilinear FOV, it is difficult to obtain full-range images or an omnidirectional image. For this reason, an additional processing is needed for taking a panoramic image which is resulted from the usage of multiple cameras. Then, this task might be a computational burden for a real-time image processing. In order to overcome these limitations, cameras with an omnidirectional lens [1, 2] have been developed with the related calibration algorithms [3, 4]. A camera module with an omnidirectional lens has various advantages such as the full-scale FOV, a small computation time for obtaining an omnidirectional image and the usage of a single camera. One of particular applications using the module is the surveillance system embedded on various motorcycles or bicycles. According to the research conducted by U.S. Department of Transportation [5], the collisions of motorcycles' crashes occurred in various directions: *Read-End*, *Head-On*, *Front-to-Side*: *Same Direction*, *Front-to-Side: Opposite Direction*, *Front-to-Side: Unknown Direction*, *Sideswipe: Opposite Direction*, *Rear-to-Side* and *Rear-to-Rear*. This statistics implies that motorcycles are more vulnerable than cars in traffic accidents. An omnidirectional camera module is a suitable module for recording these accidents from the full range directions. However, the usage of the lens and related camera module has been applied to limited types of cars such as police cars [6], only. In case that the omnidirectional camera module is applied to a surveillance camera in motorcycles, it is considered that additional interfaces are required using wireless communication. In general, current monitoring and control of a common black box system installed in a car use a direct interface using non-wireless communication modules. This trend is resulted from the fact that the embedded system is linked to a control board which is located on the car dashboard. It means that a driver can access to the surveillance system directly and easily. However, the direct interface is restricted in case of the usages in motorcycles. As a driver on a motorbike needs more careful driving and has limited usages of both hands, a wireless control is preferred to a direct communication protocol.

This research provides the framework of a mobile surveillance camera module with an omnidirectional lens and related image processing algorithms which can be used for a black box system in motorbikes. The following section summarizes the related knowledge and provides literature reviews. The overall framework

† Hyunsoo Lee is the presenter of this paper.

is provided in Section 3. The image unwrapping algorithm and wireless control are suggested in Section 4 and 5, respectively. Then, the effectiveness of the developed prototype is explained in Section 6.

2. BACKGROUND AND LITERATURE REVIEWS

According to Struthers, et al. [7], the main characteristics of Action Camera (AC) are summarized into the terms: *Compact*, *Lightweight* and *Mobile*. The initial objective of ACs was to record activities in extreme sport and these devices are used in many outdoor activities. The representative commercial AC brand is *GoPro* [7, 8].

Fig.2 Commercial ACs embedded on motorcycles and helmets.

As shown in Fig. 2, these ACs can be installed on motorbikes and used for surveillance cameras or modules for a motorcycle's black box system. However, the existing ACs are limited in the fact that usual ACs' lens have rectilinear FOVs, as discussed in the previous section. In order to overcome these limitations, this research study provides the framework of a mobile omnidirectional AC and develops its prototype. As provided in the previous section, the full directional image can be acquired easily using an omnidirectional lens. Several research studies and applications have provided related examples using the lens (Table 1).

Table 1 Application domain and uses of omnidirectional lens.

Main Application Domains	Uses of Omnidirectional Lens
surveillance and control	Human-robot interaction [9]
navigation	Autonomous helicopter [10], Robot navigation [11]
feature tracking	Omnidirectional feature extraction [12]
image reconstruction	3D data recovery and reconstruction [13, 14]

As an image using an omnidirectional lens is a donut-shaped image, additional image processing tasks are required for helping humans' understandings. This process is called as the unwrapping process (Fig. 3).

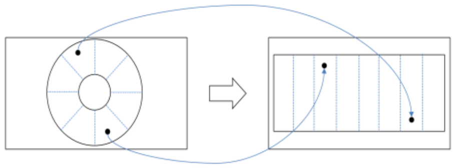


Fig.3 Unwrapping process of an omnidirectional image.

The unwrapping process consists of three steps: Preprocessing (Cartesian-to-Polar coordinate mapping), Coordinate conversion (Polar-to-Cartesian coordinate mapping) and Post processing tasks (Cartesian-to-Cartesian coordinate mapping), in general. As shown in (1), the preprocessing tasks ($g \circ f$) includes the centering process from a pixel coordinate (x, y) in a taken catadioptric image to (x', y') using the lens's center positions. Then, the coordinate is converted to (x'', y'') in the polar coordinate system.

$$(x, y)_c \xrightarrow{f} (x', y')_c \xrightarrow{g} (x'', y'')_p \quad (1)$$

where, $(x, y)_c$ is a coordinate in Cartesian system and $(x, y)_p$ is a coordinate in Polar system

The following step is a coordinate conversion process (h) where the polar coordinate system is converted into a new Cartesian coordinate system as shown in (2).

$$(x'', y'')_p \xrightarrow{h} (x''', y'''')_c \quad (2)$$

Then, the unwrapped image is constructed using several additional image processing (3) such as rectification of several distorted image sections, image rotations / transportations and cropping.

$$(x''', y'''')_c \xrightarrow{i} (x'''', y''''')_c \quad (3)$$

While (2) is performed by the direct coordinate conversion using the trigonometric functions and Pythagorean theorem in general, many effective algorithms and processing methods have been suggested for the less distorted image and the more fast conversion in (1) and (3).

This research develops a mobile surveillance camera which can be used in motorbikes. As discussed in the previous section, wireless controls are considered as a suitable communication interface in the application. There are many wireless controlled cameras including a camera module in an unmanned aircraft system [15]. Ye et al. [16] investigated and summarized the related communication methods, applications and several algorithms in wireless video surveillance systems. In general, IEEE 802.11 (Wi-Fi), IEEE 802.16 (WiMax), IEEE 802.15.4 (ZigBee) and IEEE 802.15.1 (Bluetooth) are used for wireless communication protocols in these camera systems. Section 5 provides the detail message specification and implementations for a wireless camera module with omnidirectional lens.

3. FRAMEWORK OF WI-FI

OMNIDIRECTIONAL CAMERA SYSTEM

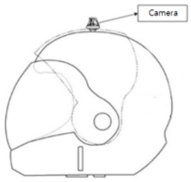


Fig.4 Conceptual image of an omnidirectional camera on a helmet.

3.1 Design of omnidirectional camera lens

Fig. 4 shows the conceptual Wi-Fi omnidirectional camera system which is installed on a motorbike helmet. As the main module of the camera is an omnidirectional lens and it is located on the helmet, the vertical degree of FOV is settled with the range between -15°~30°. Table 2 provides the detailed specifications of the omnidirectional lens.

Table 2 Specification of omnidirectional lens.

Lens Design Indicator	Specification
horizontal degree of FOV	0° ~360°
vertical degree of FOV	-15° ~30°
effective focal length	1.51mm
Overall length	Less than 30mm
image sensor	1/2.5" CMOS
effective pixel	$2x10^6$ pixel

3.2 Architecture of camera module

The developed lens is mounted on the embedded system of the omnidirectional camera. Fig. 5 shows the main components of the embedded system.

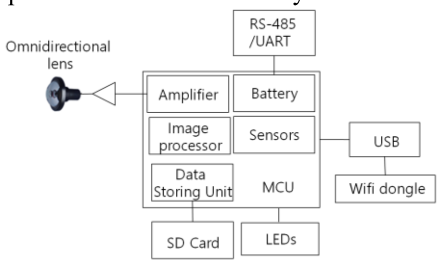


Fig.5 Embedded system of thee Wi-Fi mobile surveillance camera.

As shown in Fig. 5, the omnidirectional lens is connected to the machine control unit (MCU). MCU consists of several modules: Image amplifier, Image processing units, Data storing unit, Power supply unit, Sensing units and others. The taken image information is amplified using the image amplifier module and the image processing unit converts the information with the defined image resolution (1080 x 1920). Then, the catadioptric image is processed using an unwrapping algorithm which is suggested in the following section. While other surveillance camera systems store the taken image frames only, the developed system stores unwrapped image frames as well as the original image frames. In order to monitor the recorded frames in other computers, these processed image frames are saved in a secure digital (SD) card by Data storing unit. The power supply and control unit has an UART-typed RS-485 module for recharging its battery. As the camera systems has a role of a black box system for a motorcycle, a developed sudden motion sensor is installed using an acceleration sensor and other sensors. The sensor detects the sudden motion changes or impacts with the predefined algorithms. When an impact is detected, the camera system operates a buzzer and LEDs for delivering a warning signal to a driver. In addition, several promised messages can be sent to a driver's mobile phone in case of keeping a Wi-Fi connection. Fig. 6 shows the image processing procedures of the developed system.

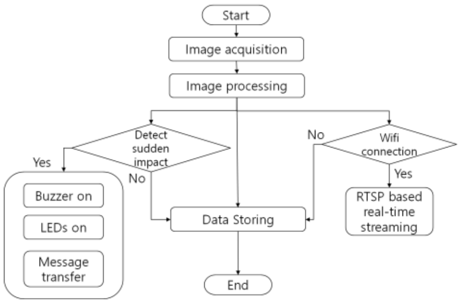


Fig.6 Image processing procedure of the mobile surveillance camera.

The camera system has several LEDs and a passive buzzer which are used for giving several status of the system such as a detection of impacts, power shortage, Wi-Fi connections and others. Wi-Fi connection is achieved using an installed Wi-Fi dongle. The installed Wi-Fi module has both functions: transmitting Wi-Fi signals and receiving Wi-Fi signals. The message transfer and handlings are achieved in MCU with the Wi-Fi module. The detailed logics and implementations are provided in Section 4 and 5.

4. IMAGE UNWRAPPING PROCESS

This section provides an unwrapping algorithm and the detailed procedures embedded on the camera module. As discussed in Section 2, the unwrapped image is considered as an image for helping a better understanding than the taken original image.

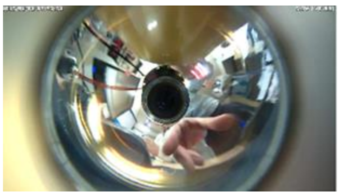


Fig.7 An original image taken from the developed

camera.

Fig. 7 shows an unprocessed image taken from the developed omnidirectional camera. The image has a donut-shaped catadioptric region. While the unwrapping process is an important task in the camera system, the processing time and the obtained quality have a trade-off relationship. As general commercial surveillance system is executed in real-time, a slow processing speed might generate additional burdens of image buffers in the camera system. For this reason, an image processing algorithm is required considering the quality of processed image and its processing time simultaneously.

As the first preprocessing task, the outer radius (R_2) and the inner radius (R_1) of the donut-shape are extracted with its center coordinate point (c_x, c_y). While the calculation of these parameters can be achieved using the preliminary calibration methods [17] and related camera parameters theoretically, it is considered that the shaking degree of motorbikes is higher than that of cars comparatively. This fact indicates that the usage of pre-estimated processing parameters might generate inaccurate unwrapping results. In order to prevent these errors, the template matching between the pre-calibrated donut-shapes regions and the acquired regions is fulfilled. Then, these parameters are modified.

Then, the donut-shaped regions are cropped from the original image and the relative coordinate (x', y') of an image pixel (x, y) is calculated using (4).

$$(x', y') = (x, y) - (c_x, c_y) \tag{4}$$

After the centering conversion of the regions, the radial coordinate (ρ) and the azimuth (θ) of (x', y') in the polar coordinate system is obtained using (5) and (6).

$$\rho = \sqrt{(x')^2 + (y')^2} \tag{5}$$

$$\theta = \tan^{-1}(y'/x') \tag{6}$$

Then, the converted polar coordinate is unwrapped to a new Cartesian coordinate (x'', y'') .

$$(x'', y'') = (R_2 - \rho, \rho \cdot \theta) \tag{7}$$

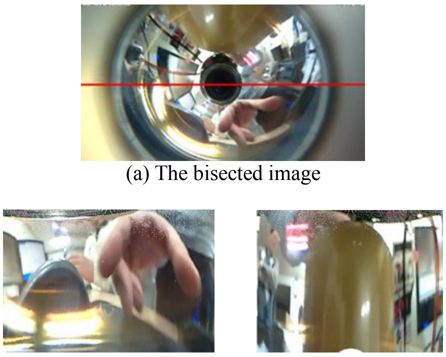
While a general coordinate conversion is executed using (7), the research applies the method of Kadmiri and Masmoudi [4] with the pre-calibrated lens' parameters for calculating an unwrapped coordinate (x''', y''') .

$$(x''', y''') = (\lceil (R_2 \cdot \theta) \cdot \alpha_1 \rceil + c_x, \lceil (R_2 - \rho) \rceil \cdot \alpha_2 + c_y) \tag{8}$$

where, $\lceil . \rceil$ is the rounded-off value of $\cdot$

and, $\alpha_1, \alpha_2 \in [0,1]$ are the unwrapping parameter

As the azimuth in (6) is the radian value, the unwrapping transformation using (8) generates the overlapped regions in the conversion of the half bottom regions and the half top regions. In order to prevent the situation, the original image is bisected with respect to its vertical axis. Then, the conversion are performed in each semicircle. In order to decrease distorted pixels and regions, the nearest-neighbor color interpolation using pre-measured sections is applied additionally. These unwrapped images consist of two parts (the front side and the rear side) in this application. While several research studies [4, 18] generates a panoramic image, the generation of the two unwrapped images helps a viewer to understand the front and the rear situations more clearly. Fig. 8 (a) shows a bisected image in Fig. 7. Fig. 8 (b) and (c) show the unwrapped image of the front side and the rear side, respectively.



(a) The bisected image

(b) The front side unwrapped image

(c) The rear side unwrapped image

Fig.8 The bisected original image and two unwrapped image.

The following section provides the integrations between the camera module and the wireless control using Wi-Fi communication protocol.

5. WIRELESS CONTROL OF SURVEILLANCE CAMERA

5.1 Wi-Fi based wireless communication

As the developed camera system can be used in various types of motorcycles, its direct controls and configurations settings are restricted comparatively than similar systems in cars. For this reason, wireless control is considered. As discussed in Section 2, there are several wireless communications protocols such as Wi-Fi, Bluetooth, ZigBee and others. Many research studies including Lee, Su and Shen [19] compared and analyzed the characteristics of each protocol and provided various applications. With respect to the communication protocols in transportations, IEEE 802.15.1 (Bluetooth) is one of the popular wireless communication protocols connecting transportations and a mobile device. Several research applications [20, 21] adopted Bluetooth with several advantages: Simple connection, Free of charge, Less battery use, Wireless communication without additional internet environment. However, this protocol is limited in the fact that the maximum data transfer rate is 1Mbps only. This fact implies that the image data transfer between two devices is restricted in real-time.

In order to overcome this limitation, another protocol (IEEE 802. 11 a/b/g – Wi-Fi) is adopted in this application. As its maximum signal transfer rate is 54 Mbps, Wi-Fi is considered as a more suitable communication protocol for transferring motion frame data. When Wi-Fi environment is configured, the most important task is to identify the location and usages of Access Point (AP) as a prerequisite condition. The developed camera system makes AP be placed in the embedded system using an installed Wi-Fi dongle, shown in Fig. 5. It indicates that the camera system has a role of a Wi-Fi hub. Fig. 9 shows the wireless communication between the camera embedded system and a driver's mobile phone using Wi-Fi.

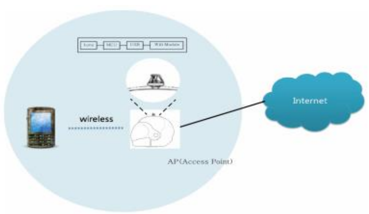


Fig.9 Wi-Fi based wireless communication.

5.3 Wireless Control and RTSP Image Streaming Transfer

As provided in Section 3 and Section 4, the unwrapping process is performed in MCU. The image processing is executed using abilities of the installed GPU in MCU, then the both images are streamed to a mobile phone. The streaming protocol follows *Real Time Streaming Protocol* (RTSP). As shown in Fig. 9, the camera system and the mobile phone have roles of a RTSP server and a RTSP client, respectively, using the installed Wi-Fi module. Then, the image streaming is executed using Wi-Fi protocol and the predefined RTSP data.

Table 3 Control and RTSP image streaming transfer.

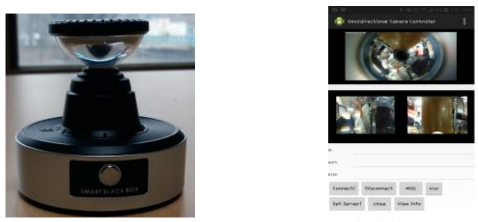
Control Items	Detailed Contents
power-off of Black box	- Requester : Mobile phone - Function executor : Camera module (power off and the reply of the result)
battery charging state	- Requester : Mobile phone - Function executor : Camera module (measuring charging rate of the battery and the reply of the information)
WI-FI / RTSP Connection	- Requester : Mobile phone - Function executor : Camera module (AP Activation and the reply of the result)
Information of SD card	- Requester : Mobile phone - Function executor : Camera module (Check of available memory in SD card and the reply of the result)
Configuration of recording image frame number	- Requester : Mobile phone - Function executor : Camera module (Setting of requested image frame number and the reply of the result)

Wireless controls are achieved using the transfer of the predefined and secured control messages. Table 3 describes several wireless control items using the predefined messages.

As described in Table 3, the main control device is a mobile phone which is possessed by a motorcycle driver. When a control message is transferred to the camera system, the surveillance system executes the order with predefined logics and replies the control results to the phone. The detailed wireless communication is executed using Wi-Fi based socket communication. An operator can control the surveillance camera system using his/her mobile phone using the provided methods.

6. IMPLEMENTATION OF WIRELESS OMNIDIRECTIONAL CAMERA SYSTEM

This section provides the implemented prototype of the wireless controlled omnidirectional camera system. Fig. 10 (a) shows its prototype.



(a) The developed camera system

(b) Android app as a controller

Fig.10 Implemented camera system and Android control app.

The developed camera system can be installed on a motorbike helmet using stickers. As shown in Fig. 10 (a), the camera system pursues a minimal interface design with one button. The button is used for turning the system on/off manually. The detailed controls are performed using the developed Android app in a driver's mobile phone. Fig. 10 (b) shows the transferred image streaming from the camera module to a mobile phone.

7. CONCLUSION AND FURTHER STUDY

While a surveillance camera system is considered as an essential module in contemporary transportations, its usages in motorbikes are limited for several reasons. In order to overcome these limitations and to capture images from full directions surrounding the transportation, this research suggests the framework of an omnidirectional camera black box system and its controls.

The taken catadioptric image frame is unwrapped using the provided algorithm with the considerations of its processing time and qualities in real-time. The control of the developed camera system is performed using Wi-Fi based wireless communication protocol. The unwrapped streaming is transferred using RTSP communication and the detailed controls are executed using the secured control message transfer and Wi-Fi socket communication method.

As further studies, unwrapping algorithms with less distortions are desired with guaranteeing a real-time image processing. In addition, various services using GPS, sensors and other smart modules embedded on a mobile phone can be integrated with the developed system.

8. ACKNOWLEDGEMENT

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