Illegal Photograph Detection under Modulated LED Illumination

Kouhei Uno
Hokkaido University
Sapporo, Japan
kouhei@ist.hokudai.ac.jp

Arata Hirano
Hokkaido University
Sapporo, Japan
hirano@ist.hokudai.ac.jp

Hiromichi Hashizume
National Institute of Informatics
Tokyo, Japan
has@nii.ac.jp

Masanori Sugimoto
Hokkaido University
Sapporo, Japan
sugi@ist.hokudai.ac.jp

***Abstract*—Nowadays, almost everyone has a smartphone and can easily take pictures. Consequently, illegal acts such as photographing or video-recording copyrighted works and uploading them to the internet are reported as a growing problem in our society. This paper proposes a method for detecting such illegal photography. By illuminating copyrighted works with an LED light emitting orthogonal frequency division multiplexing multicarrier signals and utilizing the feature of exposure time ratio in a rolling shutter camera, it is possible to distinguish between photographs taken by authorized and unauthorized cameras. The evaluation experiments confirmed that the proposed method could correctly identify photographs taken by authorized and unauthorized cameras.**

***Index Terms*—Modulated light, Illegal photographs, LED, Watermark, Rolling shutter camera**

I. Introduction

Illegal photography acts that infringe on copyright and privacy are a growing problem in our society, and there is currently no means to successfully prevent such acts. This paper proposes a method to detect illegal photographs automatically that is expected to be deployed at museums and art galleries where taking photographs of exhibits without permission is prohibited.

Some existing works have examined detecting illegal photography acts by identifying cameras through noise patterns of their image sensors [1] and the frequency of power distribution networks [2], and identifying pirated movies created by video-recording their originals played on a liquid crystal display (LCD) or screen [3]. However, these methods need multiple photographed images for illegality detection, which differs from the proposed method that needs only a single image.

Our previous work illustrated that a rolling shutter camera (Fig. 1) works as a frequency filter of an optical signal and receives frequencies dependent on the values of its exposure time ratio [4]. Therefore, by taking photographs under LED orthogonal frequency division multiplexing (OFDM) multicarrier waves, the frequency spectra of individual carriers differ when the exposure time ratios between cameras differ. Thus, watermarks are deposited on photographs by frequency spectra, and by setting a designated exposure time ratio to an authorized camera, it is possible to distinguish between photographs taken by authorized and unauthorized cameras.

Manuscript date of current version January 8, 2019.

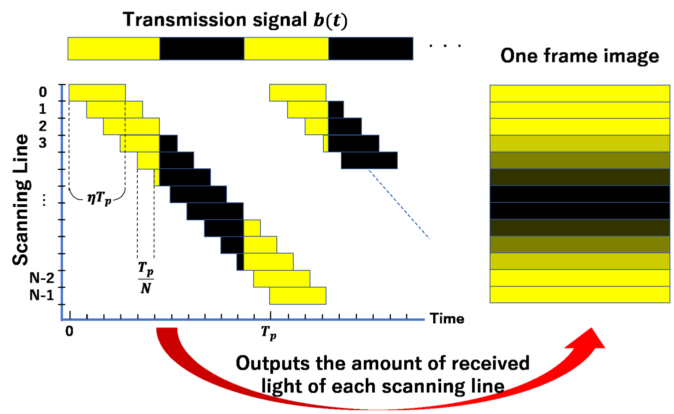

Fig. 1. Line-by-line scan implemented in a rolling shutter camera

LiShield [5] emits an on-off-keying modulated signal from an LED light such that a visible stripe pattern is overlaid to degrade an image taken by a rolling shutter camera. LiShield also uses only a single image, and the proposed method overlays a visible stripe pattern and embeds an invisible pattern as a watermark by frequency spectra.

The experiment confirmed that photographs taken by cameras having different exposure time ratios showed different spectral distributions of received signals from the LED light and that the different spectral distributions could identify photographs taken by authorized and unauthorized cameras.

II. Proposed Method

A. Photography action of camera

As shown in Fig. 1, when an exposure time ratio η $(0 < \eta < 1)$ and a frame period T_p of a camera are given, its exposure time is expressed as ηT_p. A transmission signal $b(t)$ from an LED light is composed of OFDM multicarrier waves whose fundamental frequency is $1/T_p$. The k-th order Fourier coefficient of $b(t)$ is expressed as shown in Eq. (1).

$$\tilde{b}_k = \frac{1}{T_p} \int_0^{T_p} b(t) e^{\frac{-j2\pi kt}{T_p}} dt \tag{1}$$

When the sensitivity of all the line sensors is assumed to be equal and the number of line sensors is N, the intensity

978-1-5386-9151-9/19/$31.00 ©2019 IEEE

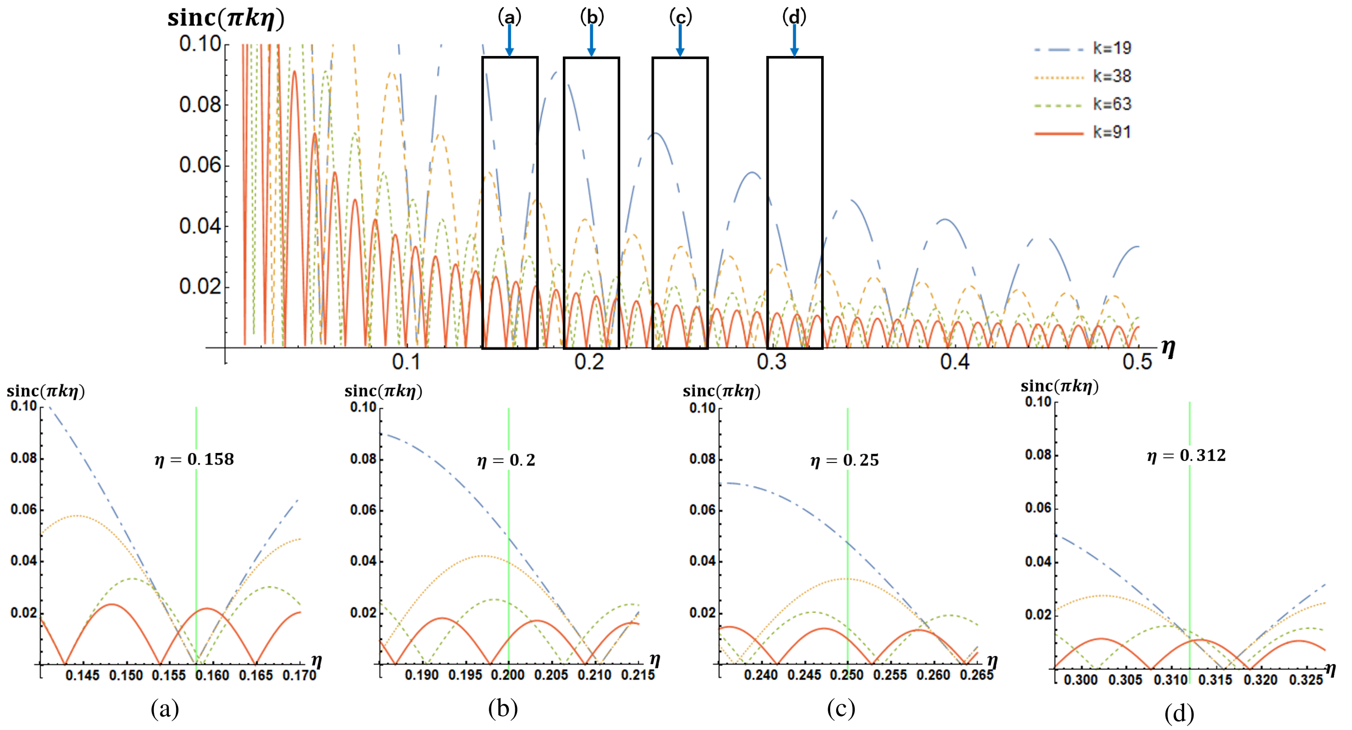

Fig. 2. Frequency spectra of multicarrier waves composed of the 19th, 38th, 63rd, and 91st order sinusoidal waves. (a) When η is set to 0.158, $\mathrm{sinc}(\pi k\eta) = 0$ holds ($k = 19$, $k = 38$, and $k = 63$). Their spectra become 0 and the spectrum of the 91st carrier wave is detected. (b–d) When η is set to the other values, all the spectra of the multicarrier waves are detected.

value of the n-th line sensor ($n = 0, 1, ..., N-1$) is given as Eq. (2).

$$I_n = \frac{A}{T_p}\int_{\frac{nT_p}{N}}^{\frac{nT_p}{N}+\eta T_p} b(t)dt \qquad (2)$$

A is a transfer coefficient between an LED light and a camera and can be regarded as $A = 1$ without loss of generality. By converting one frame image $I = (I_0, I_1, ..., I_{N-1})^T$ into a spatial Fourier series, its k-th order coefficient $\tilde{B}_k$ is obtained as

$$\tilde{B}_k = \frac{1}{N}\sum_{n=0}^{N-1} I_n e^{-j2\pi kn} \quad (-\frac{N}{2} \leq k \leq \frac{N}{2}). \qquad (3)$$

By substituting Eq. (2) into I_n of Eq. (3) and conducting the inverse Fourier transform, the following equation is obtained.

$$\tilde{B}_k = \eta e^{j\pi k\eta}\mathrm{sinc}(\pi k\eta)\tilde{b}_k \qquad (4)$$

Therefore, the k-th order frequency component $\tilde{b}_k$ of the transmission signal $b(t)$ can be obtained from the k-th order Fourier coefficient $\tilde{B}_k$ of the photographed image. The coefficient $\eta e^{j\pi k\eta}\mathrm{sinc}(\pi k\eta)$ of $\tilde{b}_k$ in Eq. (4) is derived from the integration sampling of a rolling shutter camera (Eq. 2) and works as a frequency filter.

B. Frequency filter by sinc function

In Eq. (4), η and $e^{j\pi k\eta}$ do not become 0. However, $\mathrm{sinc}(\pi k\eta)$ can be 0 depending on values k and η. Thus, the spectrum magnitude of the k-th order carrier wave varies by changing the exposure time ratio η. Therefore, when a specific exposure time ratio η_A to an authorized camera is established, the frequency spectrum of a designated carrier wave in a photograph taken by it can be detected. For example, in Fig. 2, the exposure time ratio of an authorized camera is set to $\eta_A = 0.158$ and the other cameras are set to different values such as $\eta_U = 0.2, 0.25$, and 0.312. Then, only the frequency spectrum of the 91st order carrier wave is detected in a photograph taken by the authorized camera, as shown in Fig. 2 (a). In photographs taken by cameras with different exposure time ratios, the frequency spectra of all the carrier waves are detected, as shown in Fig. 2 (b)–(d), and these differ from those taken by the authorized camera. Thus, spectrum distributions of the multicarrier waves obtained from photographs perform the role of watermarks and allow illegal photography to be detected.

As η_A is a key value for illegal photography detection, it should be dynamically changed and notified to only an authorized camera. In addition, this work investigates a method to randomly choose η_A and notify it to an authorized camera in a secure manner. When the value of η_A is changed, the frequencies of carrier waves emitted from an LED light are changed accordingly. The frequencies of carrier waves must be sufficiently high to avoid flicker and not be perceivable to the human eye; how to theoretically find pairs of η_A and frequencies of multicarrier waves are other issues to be investigated.

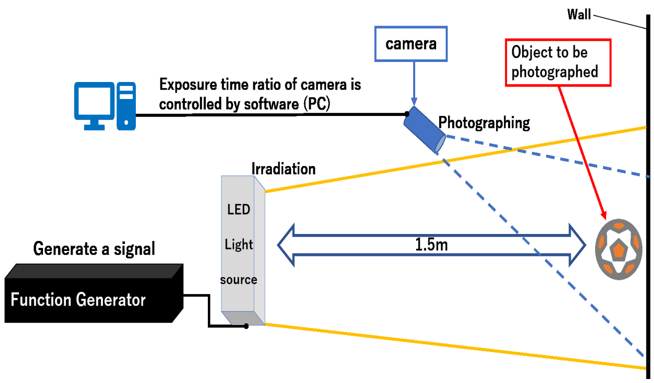

Fig. 3. Experimental setup

III. Evaluation Experiments

A. Experimental environment

Evaluation experiments were conducted using a 60 fps USB 3.0 camera (Point Grey FL3-U3-13S2C-CS) with 1280×1000 pixels and a white LED floodlight (W-LITE DL-FL-001). Transmission signals were then generated using a function generator (NF Corporation WF1948) connected to the LED light. The line sensors of the camera are only active during a part of the period and inactive otherwise (called dead time). By measuring the dead time of the camera, the fundamental frequency of the signal emitted from the LED light was set to 120 Hz. The multicarrier signal was composed of the 19th (2280 Hz), 38th (4560 Hz), 63rd (7560 Hz), and 91st (10920 Hz) sinusoidal waves and the exposure time ratios of the cameras were set to $\eta = 0.158$ (shutter speed: 1.201 ms), $\eta = 0.2$ (1.522 ms), $\eta = 0.25$ (1.905 ms), and $\eta = 0.312$ (2.379 ms), respectively, as shown in Fig. 2. A picture of cherry blossoms and a soccer ball were chosen as objects to be photographed under the LED illumination. The experiment was performed in a room where fluorescent lamps installed on the ceiling were turned on, and the distance between the LED light and the objects to be photographed was set to 1.5 m, as shown in Fig. 3.

B. Experiment and result

Images photographed by cameras with different exposure time ratios under LED illumination are shown in Fig. 4. The distributions of their frequency spectra are shown in Fig. 5. The horizontal dashed lines in Fig. 5 represent the maximum spectrum magnitude of photographs taken without the LED illumination. These lines are used as reference levels to detect frequency spectra of individual multicarrier waves. Vertical dashed lines represent the lowest order of carrier waves composing the OFDM multicarrier waves and making flicker imperceptible. Therefore, the spectra on the left side of that line were ignored for the purpose of identifying illegal photography.

The illegality of photographed images was determined in the following procedure.

step 1: When one or more frequency spectra of the 19th, 38th, or 63rd order waves are detected, the image is illegal.

step 2: If the frequency spectrum of the 91st order wave is not detected, the image is illegal.

step 3: If only the frequency spectrum of the 91st order wave is detected, the image is legal.

In this experiment, frequency spectra of the 19th, 38th, and 63rd order waves were used as evidence to judge the illegality of photographs, and the frequency spectrum of the 91st order wave was used to judge their legality. By using multiple watermarks by multiple frequency spectra as evidence, illegality detection can be more robust.

The illegality detection was conducted as follows. First, from the photographs taken by the cameras with $\eta = 0.2$ and $\eta = 0.25$, frequency spectra of the 19th and 38th order waves higher than the reference level were detected as shown in Fig 5. Thus, the photographs were judged as illegal (step 1). In the photographs taken by the cameras with $\eta = 0.158$ and $\eta = 0.312$, the frequency spectra of the 19th, 38th, and 63rd order waves were lower than the reference level. However, the photographs taken by the camera with $\eta = 0.312$ did not show the frequency spectrum of the 91st order wave higher than the reference level and that with $\eta = 0.158$ showed a higher spectrum magnitude than the reference level. Thus, the photographs taken by the cameras with $\eta = 0.312$ were judged as illegal (step 2), and those with $\eta = 0.158$ were judged as legal (step 3).

IV. Conclusions and Future Works

This paper proposes a method for detecting illegal photography under an LED light emitting OFDM multicarrier signals. We explained mathematically how a rolling shutter camera worked as a frequency filter by changing its exposure time ratio, thereby allowing legal and illegal photographs to be distinguished. The evaluation experiment confirmed that the proposed method could identify photographs taken by an authorized camera with a specified exposure time ratio and those taken by unauthorized cameras having different ratios. Our future work will focus on the following issues.

1) The robustness of our proposed method with respect to compressed, deformed, and edited images.
2) Performance comparison with existing methods.
3) Application development for smartphones.
4) Intensive evaluation in real-world situations, for example, in museums or art galleries.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 17K19952.

References

[1] Mo Chen, Jessica Fridrich, Miroslav Goljan, and Jan Lukáš : Determining Image Origin and Integrity Using Sensor Noise, *IEEE Transactions On Information Forensics and Security*, Vol. 3, No. 1, pp.74-90, (2008).

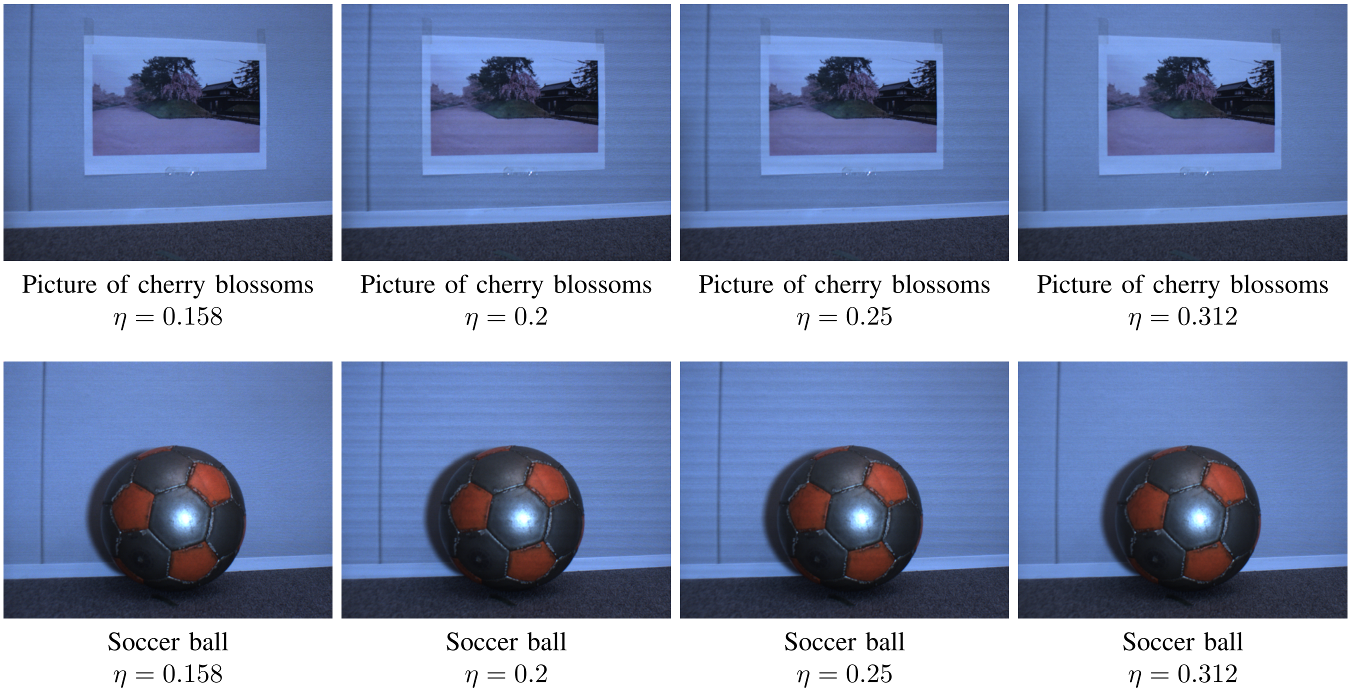

Fig. 4. Photographed image of each exposure time ratio

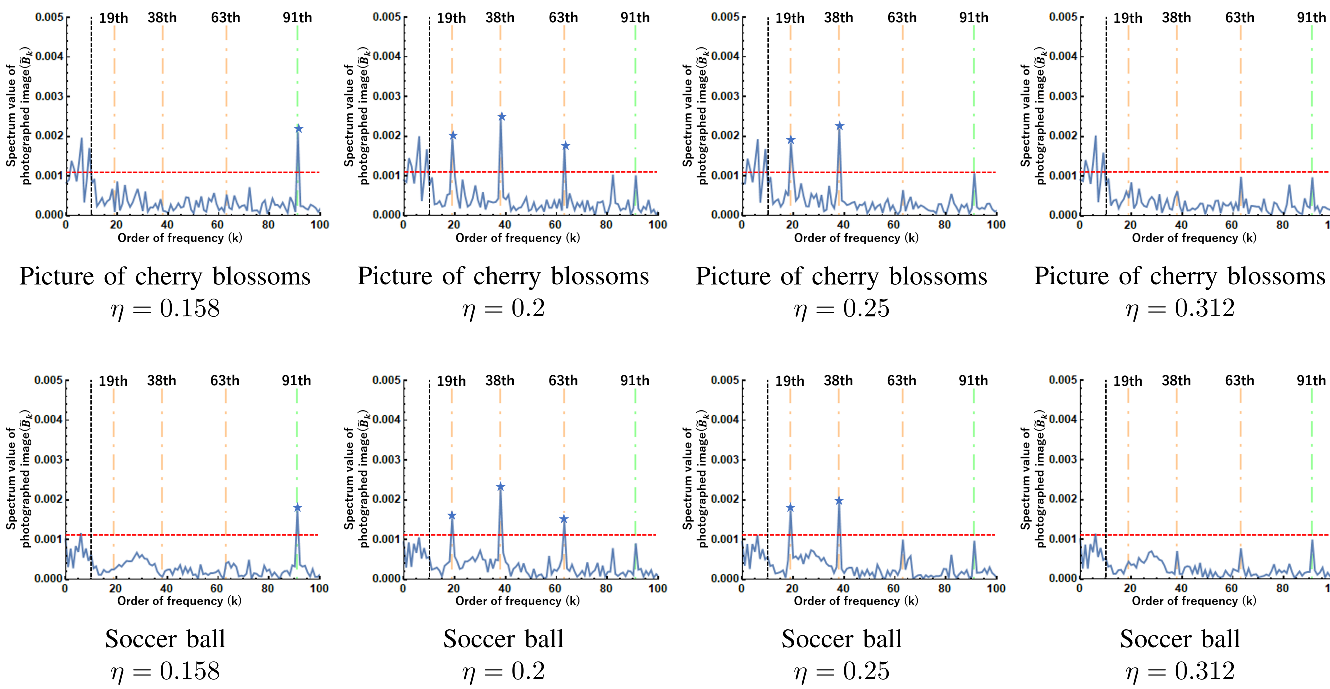

Fig. 5. Spectrum distribution of each exposure time ratio

[2] Adi Hajj-Ahmad, Andrew Berkovich, and Min Wu : Exploiting Power Signatures for Camera Forensics, *IEEE Signal Processing Letters*, Vol. 23, No. 5, pp.713-717 (2016).

[3] Adi Hajj-Ahmad, Séverine Baudry, Bertrand Chupeau, Gwenaël Doërr, and Min Wu : Flicker Forensics for Camcorder Piracy, *IEEE Transactions On Information Forensics and Security*, Vol. 12, No. 1, pp.89-100 (2017).

[4] Arata Hirano, Shota Shimada, Hiromichi Hashizume, and Masanori Sugimoto : Selective Visible Light Communication for Multiple Video Cameras using a Single Light Source, *In Proc. of ACM SenSys 2018*. ACM, Shenzhen, China, pp. 335-336, (2018).

[5] Shilin Zhu, Chi Zhang, and Xinyu Zhang : Automating Visual Privacy Protection Using a Smart LED, *In Proc. of MobiCom'17*, Snowbird, UT, pp.329-342 (2017).