Active optical sensing with randomized coded light for intentional interference tolerance

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***Abstract*— We propose active sensing scheme to strengthen the security on the stage of collecting information using an image sensor. The selective-signal detective image sensor is employed to detect only the reflected light from incident light including attacking light modulated by modulation frequency.For strengthening the security, proposed active sensing scheme have employed the coded light instead of the modulated light. But using the coded light as is, the integration time varies on which coded light is used. The specific coded light is proposed for constant integration time. The signal-selectivity with coded light and modulated light is measured and explained. The pixel value become a peak in the case with the coded light when the sampling operation of the image sensor is fixed with the coded sampling. Comparison with fixed sampling with modulated light, overall noise increases, and SNR decreases from 5.9 dB to 2.5 dB by 57.6%.**

I. Introduction

In recent years, active optical sensing are widely used in various applications and fields [1], [2]. They are made on the assumption that the measurement data from the measurement system based on active optical sensing are correct. A direct attack on the inside of the system even if it can not be done, there is a concern that the system can be attacked by disguising the measurement result [3]. The reliability and security of the measurement are required depending on the applications. For this reason, previous works to improve information security in situations such as data communication, storage, analysis, and so on. However, the work for instrumental security at the stage of collecting information using the image sensor is still insufficient.

The instrumental security means the security of the system that consist of instrumental device such as image sensor. The structure of the instrumental system is illustrated abstractly in Fig. 1. The instrumental system measures the data of the object using an instrumental device, an image sensor, on the path A. Next, the measurement data are sent to the processing unit on the path B. Finally, the command or data are sent to outside of the system on the path C and an interface. Considering the security threat to the instrumental system, tapping or tampering can be performed on the path B or C. Conventionally, it is known that such attacks can be protected by encrypting messages and adding message authentication codes (MAC) [3]. However, a definitive protection technology against attack in this path A has not been established.

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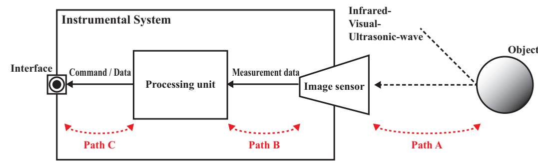

Fig. 1. Structure of instrumental system [3].

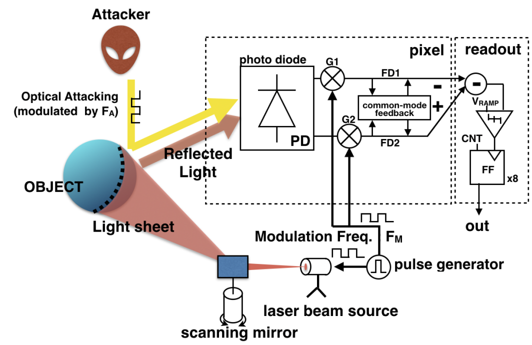

Fig. 2. Proposed active sensing scheme

Enhancing the security on the stage of collecting information using an image sensor is required in the instrumental system.

In this paper, active optical sensing scheme using the image sensor and the coded light is proposed and evaluated. In section II, the structure of the instrumental system and the weak-point of this system are explained. Then, the new coding scheme for optical sensing is introduced and explained the conversion to coded light. The measurement results with proposed coded light are showed in section III. Finally we discuss the conclusion and future tasks.

II. Proposed active optical sensing

Fig. 2 shows the proposed active sensing scheme to detect only the reflected light from incident light including attacking light modulated by modulation frequency F_A. An image sensor with selective-signal detection is employed based on modulated light as ON-OFF signal [4]. The proposed new coding scheme is based on the image sensor with the demodulation transistors illustrated in Fig. 2. The pixel circuit consist of one photodiode, two transistors for transfer gate, common-mode feedback circuit for preventing saturation and additional circuits such as source follower amplifier, row-select transistor.

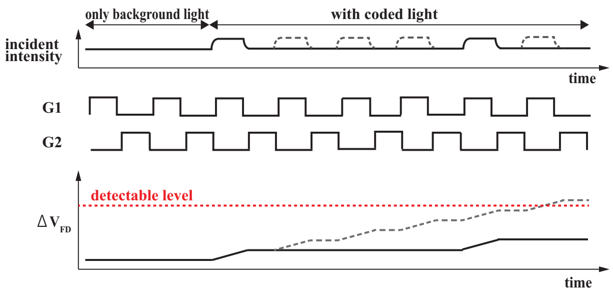

Fig. 3. Problematic situation of pixel operation with modulated light (dotted line) and coded light (solid line).

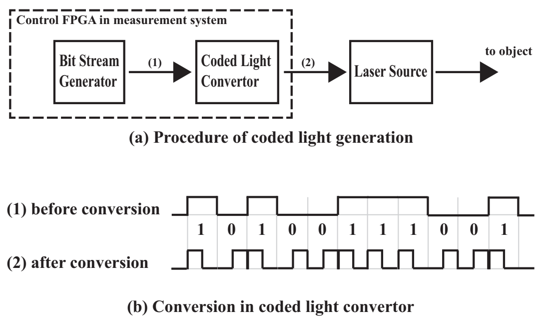

Fig. 4. Conversion scheme for new optical coded-signal: (a) Procedure of coded light generation, (b) Conversion in coded light convertor

A. Problem of previous modulation scheme

The solid line of ΔV_{FD} as shown in Fig. 3 shows the relationship between the integration time and the differential voltage ΔV_{FD}, and describes the normal operation with modulation light with the image sensor [4]. ΔV_{FD}, which means $V_{FD2} - V_{FD1}$, is the the differential voltage between floating diffusions. The signal light as ON–OFF signal is modulated with specific frequency. Therefore, the signal light always turns ON to OFF and OFF to ON. Using this light, the image sensor integrates photons from the reflected light, and increases the differential voltage between floating diffusions, ΔV_{FD}, monotonously. The dotted line of ΔV_{FD} as shown in Fig. 3 shows also the relationship between the integration time and the differential voltage ΔV_{FD} with the image sensor [4], and also describes problematic operation with coded light like as simple bit stream. As shown in Fig. 3, the problematic situation is that the coded light has the more OFF-signal than ON-signal. It makes the image sensor integrate less photons than the normal operation with modulation light because the OFF–signal can not make the differential voltage, ΔV_{FD}, bigger. So the integration time could be longer to reach the detectable level of the differential voltage, ΔV_{FD}. In the opposite case, if the coded light has the more ON–signal, the integration time could be shorter. Therefore, the integration time can vary depending on which the coded light is used. The specific coded light is required for the sensing with the image sensor [4].

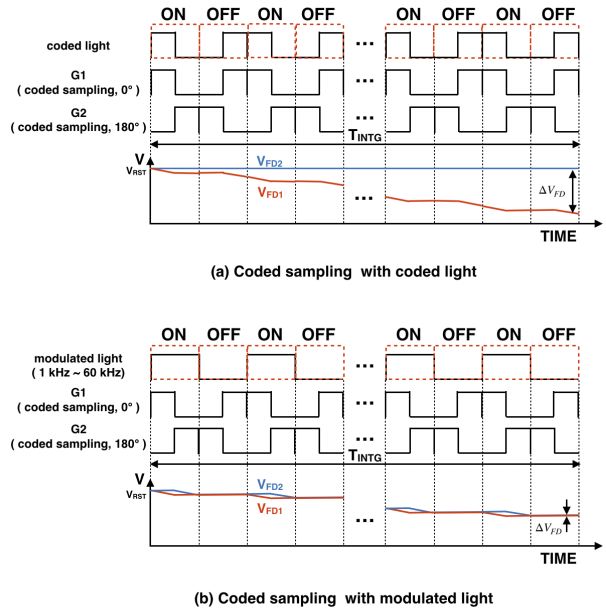

Fig. 5. Timing diagram of coded sampling with coded light and modulated light: (a) coded sampling with coded light, (b) coded sampling with modulated light.

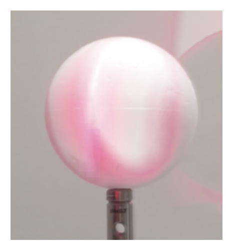

Fig. 6. target of measurement: a white ball.

B. Conversion scheme for coded light generation

Fig. 4 (a) shows a procedure of coded light generation that consist of a bit stream generator and a coded light convertor in a control FPGA in measurement system, and a laser source. In this work, a clock generator is employed for the bit stream generator in a control FPGA in measurement system. Fig. 4 (b) shows the conversion scheme for constant integration time. For keeping constant integration time, the duty 50% of signals is needed to be kept. It means that the number of bit '1' must be equal to the number of bit '0'. Similar to Manchester encoding [5], The bit '1' is converted to HIGH–LOW and the bit '0' is converted to LOW–HIGH. However, dissimilar to Manchester encoding [5], the HIGH levels in HIGH–LOW and LOW–HIGH are important for constant integration time, not the edges of HIGH–to–LOW and LOW–to–HIGH.

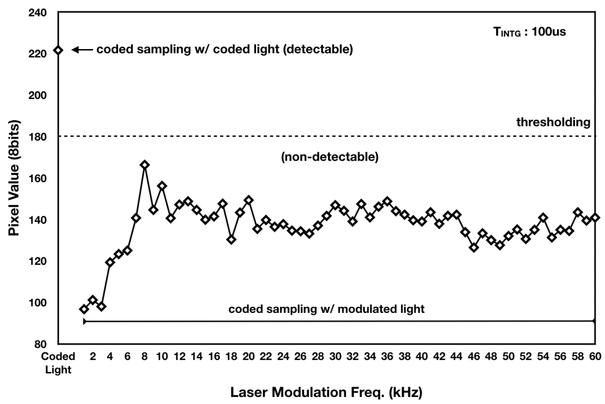

Fig. 7. Signal selectivity on coded sampling with coded light and modulated light (1 kHz ~ 60 kHz).

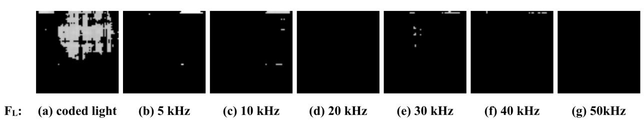

Fig. 8. Output images: (a) coded gating with coded light, (b)~(g) coded gating with various laser modulation frequency F_L = 5,10,20,30,40,50 kHz.

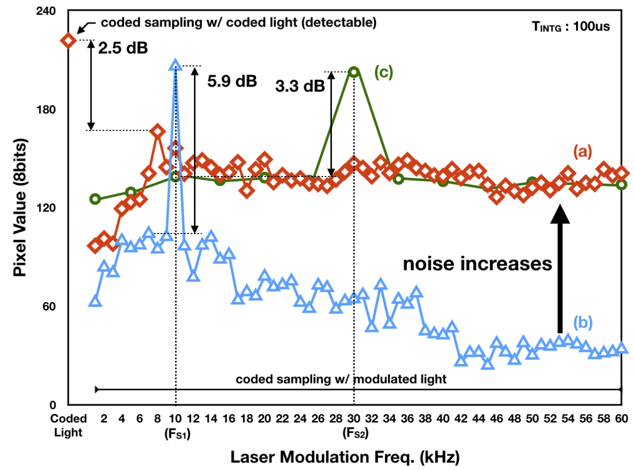

Fig. 9. Signal selectivity: (a) coded sampling with coded light and modulated light (1 kHz ~ 60 kHz), (b) fixed sampling (F_{S1} = 10 kHz) with modulated light (1 kHz ~ 60 kHz) [6], (c) fixed sampling (F_{S2} = 30 kHz) with modulated light (1,5,10,15,20,25,30,35,40,45,50,55,60 kHz).

III. Measurement results

A. Measurement Setup

The measurement system [4] is employed for the measurement using coded light. It consists of a laser source (wavelength 670 nm), the fabricated sensor with a lens mounted on a test board with FPGA, a pulse generator, a light projector for ambient illumination, and a lux meter. Fig. 5 shows the timing diagram of the control signals with coded light in the measurement. Fig. 5 (a) and (b) are illustrated two cases: the one case of coded sampling with coded light and the other case of coded sampling with modulated light. The modulated light is modulated by the modulation frequency from 1 kHz to 60 kHz. The coded light is converted on the modulated light by the modulation frequency 10 kHz. Fig. 5 (a) means the case that the image sensor wants to accumulate the only reflected light in Fig. 2. Fig. 5 (b) means the case that the image sensor wants to avoid the disguised light from a certain attacker in Fig. 2. Before the measurement, the analysis of the coded light and calibration of the coded sampling are performed for the phase adjustment between the control signal and reflected light. The target of the measurement is a white ball shown in Fig. 6. For the post-processing, after accumulating and averaging 16 frames for temporal low pass filtering, 3x3 average spatial filter is performed for spatial low pass filter. The peak values are obtained by thresholding as shown in Fig. 7.

B. Selective light Detection with coded light

Fig. 7 shows signal selectivity that is pixel values on the coded sampling with the coded light and the modulated lights modulated by various frequencies (1 kHz ~ 60 kHz). As shown by Fig. 7, only when the case is coded sampling with coded light, the pixel value becomes a peak and the cases of coded sampling with modulated light are suppressed. And the signal selectivity with coded light is confirmed in same integration time at the case with modulation light. Fig. 8 shows the output images on coded sampling with the coded light and the modulated light (F_L = 5,10,20,30,40,50 kHz). Fig. 8 (a) shows that the coded light is detected by the coded sampling. Fig. 8 (b)~(g) show that the modulated lights are ignored by the coded sampling.

C. Comparison and Discussion

Fig. 9 (a) shows signal selectivity that is pixel values on the coded sampling with the coded light and the modulated lights modulated by various frequencies (1 kHz ~ 60 kHz). And the SNR of the coded sampling is 2.5 dB. Fig. 9 (b) shows signal selectivity that is pixel values on the fixed sampling (F_{S1} = 10 kHz) with the modulated lights modulated by various frequencies (1 kHz ~ 60 kHz). And the SNR of the fixed sampling is 5.9 dB. Fig. 9 (c) shows signal selectivity that is pixel values on the fixed sampling (F_{S2} = 30 kHz) with the modulated lights modulated by various frequencies (1,5,10,15,20,25,30,35,40,45,50,55,60 kHz). And the SNR of the fixed sampling is 3.3 dB. In measurements of Fig. 9 (a), (b), and (c), the integration time T_{INTG} is $100us$. Compare with Fig. 9 (b), the overall noise increased. And SNR decreased by 57.6%. From the SNR and overall noise level of fixed sampling (F_{S2} = 30 kHz) shown in Fig. 9 (c), the coded light based on modulated light modulated by modulation frequency 10 kHz has similar results of SNR and overall noise level. Therefore, the affect to an image sensor from the coded light is similar to the case using higher modulation frequency than base modulation frequency that is used to generate the coded light.

IV. Conclusions

Instrumental security on the stage of collecting information using an image sensor is required in active optical sensing. Active optical sensing with the coded light is proposed. The duty 50% of signal is required to the specific coded light for constant integration time. The method of bit conversion based on Manchester encoding is proposed and evaluated. Active optical sensing with coded light is evaluated and the signal selectivity with coded light is confirmed in same integration time at the case with modulation light. However, the SNR of signal-selectivity decreases by 57.6% from case with modulated light. It is confirmed that the affect to an image sensor from the coded light is similar to the case using higher modulation frequency than base modulation frequency that is used to generate the coded light.

Acknowledgment

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