Random Sequence Modulation of Multiple-Gate of Indirect ToF for Handling Multi-ToF-Camera Interference

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Abstract This paper presents a new method, randomizing the modulation function of indirect time-of-flight(ToF) camera, to improve its robustness to high frequency noise from the interference of other ToF devices. It has been verified by experiment that the proposed method shows better robustness under high-frequency noise.

Keyword time-of-flight camera, interference, random sequence

1. Introduction

Recently, time-of-flight (TOF) cameras such as Azure Kinect are becoming the preferred depth-sensing technology in several applications. Those indirect ToF cameras estimate the depth from the phase shift between the modulated high frequency signal emitted from the light source and the received signal[2-3] which is demodulated by the sensor. And it is called the modulation function. Due to the theory of ToF, its accuracy is easily degraded by ambient light.

Some studies cancel the ambient light from the signal by measuring it with an additional sensor(double ramp)[1], using special modulation design[4-7], or deep learning[8-9]. But they do badly in high frequency noise which may come from the interference of other ToF devices.

This paper proposed a modulation method based on pseudo-random sequences [12-13] to cancel interference of other ToF devices. In this method, we randomize the modulation function of ToF to change its spectrum. By this, we can get a good depth result under interference.

2. Method

In the ToF cameras with traditional modulation functions such as the double ramp[1] and Square[4] method, the output of each gate can be understood as the correlation between the received signal and the gate signal. And since the signal is modulated at a fixed frequency, it will show a high correlation with close high frequency external signals from interference, leading to errors in depth estimation. So this paper modulates the ToF with random sequences based on the Direct Sequence Spectrum Spreading (DSSS) which is widely used in the wireless field to extract the target signal with noises by spreading the emitted signal. And it is also used in active-stereo to improve the SNR of laser light[12].

The double ramp method uses two sensors for depth calculating and one sensor for noise canceling. To ultimate DSSS on the double ramp method, we used a spreading code based on maximal-length sequence (MLS) [13] which is a pseudo-noise sequence consisting of values 1 and -1. We convert the value of -1 in MLS to 0 and use 1 for the laser to emit light and 0 for no light. For sensors, we modulated one sensor by the same signal as the light source and modulated another sensor by the inverted signal of light. Due to the correlation with the reference signal changes inversely, the phase shift can be easily calculated as follows:

$$\Delta\phi = (r_D - 1)\,\pi, \tag{1}$$

where the ratio rD is defined as

$$r_D = (Q1 - Q2)/(Q1 + Q2). \tag{2}$$

Q means the luminance of two sensors.

By this, the high frequency noise can be removed due to the correlation between noise and MLS sequence is small.

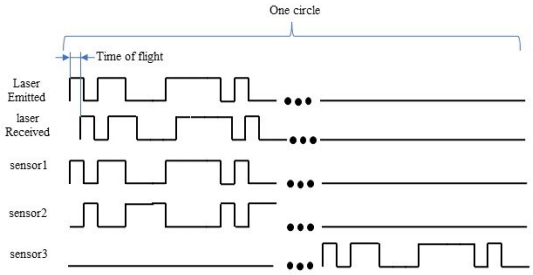

Figure 1. The signal of double ramp with DSSS

The signal of the double ramp with DSSS is shown in Fig. 1. Same as the double ramp, we use the additional sensor to cancel the ambient light, but this would hurt the

depth result due to we only use two sensors for calculating depth. And Square method[4] used 3 sensors for depth and cancel the noise by relationships between the three sensors. The two method's correlation of sensor is shown in Fig.2.

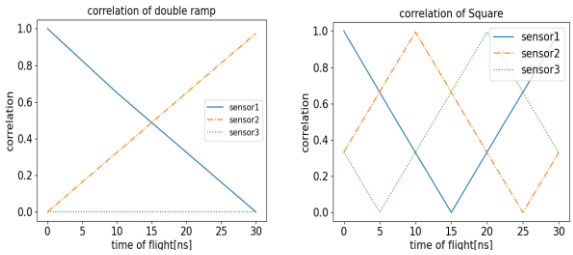

Figure 2. The signal of double ramp and Square

To combine our method with the Square method, we convert the MLS to a sequence consisting of 0,1,2 which corresponds to the sensor of Square. According to the sequence, we change the exposure pattern of the sensor to avoid the fixed frequency of the signal. Thus, the influence of high frequency noise is reduced. This method can be also used on all continuous ToF methods.

3. Experiment

To verify the effect of the proposed method, we estimate the depth of the board in 45/60 cm using the double ramp[1], double ramp with DSSS, Square[4], and Square with DSSS. And we use another ToF laser to set interference whose frequency is close to the depth estimating ToF device. The result is shown in Fig. 3.

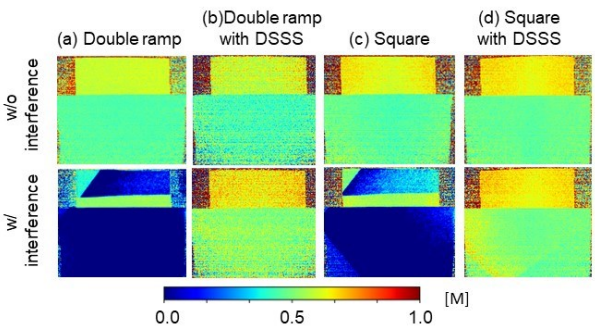

Figure 3. Result of double ramp and DSSS

All methods get a near result of 45/60 cm with similar color which means same depth when there is no high frequency noise from interference. However, when there is noise, the double ramp and Square methods are significantly influenced by the interference and the dark area is exactly the area noise illuminated, and our method reduced the influence. We will also ultimate our method on other specific modulation functions[5-7] to verify our method's effect in the future.

4. Conclusion

The effectiveness of improving robustness to high frequency noise by randomizing the modulation function of the ToF camera has been shown in this paper.

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