The accuracy analysis of TOF camera based on ANOVA

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***Abstract*--In recent years, with the development of imaging technology based on photon time of flight (TOF) measurement, the TOF camera has gradually come into the public horizon. Compared with binocular vision and structured light 3D imaging, TOF imaging system can image the scene in real time without any processing. However, it is difficult to be widely used because of the low resolution and poor depth measurement precision. Based on the imaging theory of TOF camera, the imaging error of TOF camera is analyzed under the action of many factors. After the analysis of environmental light intensity, measurement distance and target reflectivity, the analysis of variance (ANOVA) of the collected data shows that the reflectivity of objects has more influence on the imaging error.**

I. INTRODUCTION

Time-of-flight camera is an active imaging system. The 3D images can be obtained by scene illumination in self lighting system and recording the round-trip distance of photon. Attributed to the characteristics of 3D scene direct acquisition in real-time, small size, low cost, TOF camera, also known as the depth camera, shows its application potential in fields of human-computer interaction, robot location, 3D imaging reconstruction [1]. The mainstream 3D camera is a binocular vision camera and a structured light camera. These kinds of camera have high spatial precision, but the range of distance is relatively short, and the processing algorithm is complex [2]. At present, the TOF camera can directly image the measured target, the algorithm is relatively simple, the processing speed is relatively fast, and the performance of TOF camera is improving year by year [3]. Because the TOF camera is based on the principle of photon time-of-flight, it will be interfered by many factors in the imaging process, and the error of ranging imaging results is very rich. The effects of working distance, ambient illumination and target reflectivity on 3D scene imaging are analyzed in this paper. These three factors are variables that can be controlled at the same time. Therefore, the one-way analysis of variance can be realized. By analyzing the change of a certain variable, it is concluded that its influence on the imaging accuracy is remarkable. In this work, the effect of three factors on the imaging accuracy is analyzed by using the ANOVA.

II. ANALYSIS OF IMAGING ERROR OF TOF CAMERA

As the Fig. 1 shown, TOF system belongs to an active imaging mode. The difference of phase can be obtained for distance calculation by round-trip signals which are emitted from self-lighting system. Object distance from sensor and phase difference can be defined as follow:

$$d_{range} = c / 2f \tag{1}$$

$$\varphi = arctan\left[(Q_1 - Q_3)/(Q_0 - Q_2)\right] \tag{2}$$

$$d = c\varphi / 4\pi f \tag{3}$$

whereas, d_{range} is the maximum measuring distance, d is the objects distance, f is the frequency of TOF illumination, c is light speed. The more details of TOF system can be found in [4]-[5].

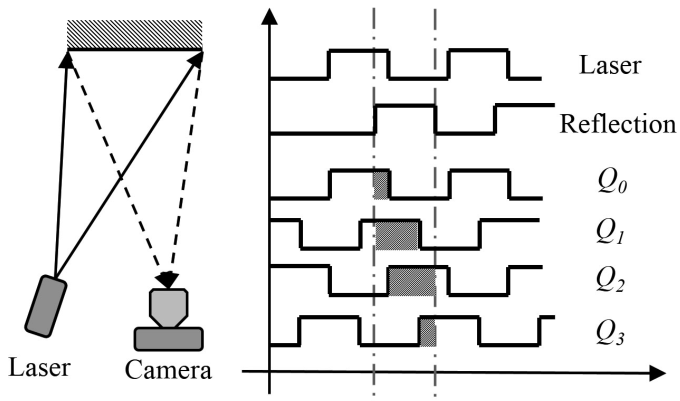
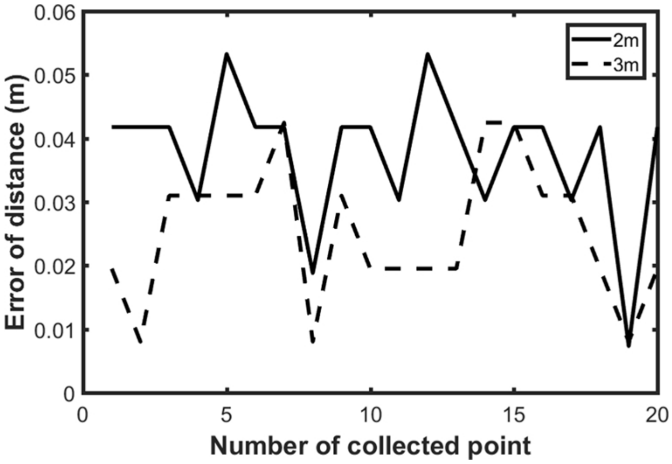
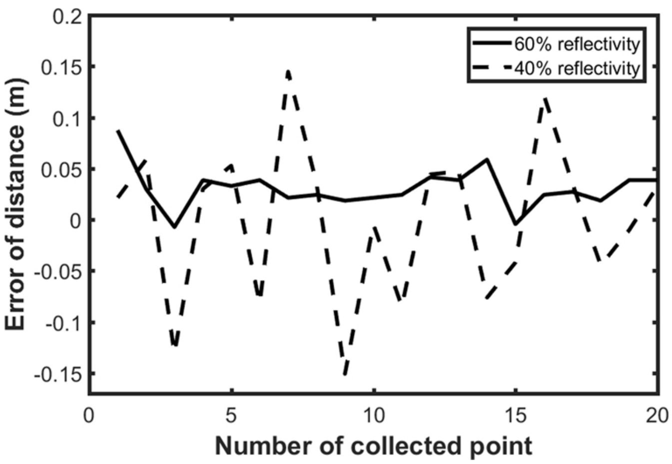


Fig. 1 The schematic diagram of TOF system.

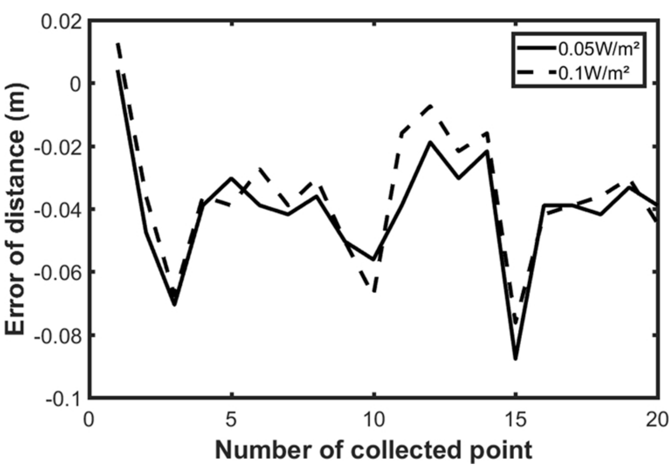
Because of geometry in space, different numbers of photons are obtained on different pixels to form a contrast image at same time. It is a statistical result. Therefore, directly affecting the imaging results, the number of effective photons should be sufficiently captured. In this work, accumulative errors was produced. We can summarize it as follows: 1) The number of received photons will change with the change of detection range. The intensity of the relative illumination decreases as the detection distance becomes far away, because the increase of the photon emission causes the information to be lost. This leads to a reduction in precision. 2) Accumulating some irrelevant information on each pixel, ambient light will cause the pixel saturation, shot noise and other uncertain factors. 3) Target reflectivity in TOF imaging technology is a key problem. TOF imaging technology is based on the returned photons. Due to the different reflectivity on the plane of the same distance, the number of returned photons is also different. The obtained contrast by different reflectivity is not the result of ranging imaging. So, it is a kind of strong interference. The data collection and analysis of these three cases are carried out in this paper. Three cases are discussed as follow: 1) Fixed objects reflectivity, change the distance without ambient light. 2) Fixed objects distance, change the reflectivity without ambient light. 3) Fixed objects distance and reflectivity, change the intensity of ambient light.



(a) The error data without ambient light at the distance of 2m and 3m under the fixed reflectivity 40%.



(b) The error data without ambient light at fixed distance 2m under the reflectivity 40% and 60%.



(c) The error data at fixed distance 2m and reflectivity 40% under the ambient light intensity 0.05 W/m^2 and 0.1 W/m^2.

Fig. 2 The errors data of range maps collected under different condition.

III. Analysis of Variance

ANOVA can identify whether a certain factor has significant influence on dependent variables in a group of experiments. The fundamental problem is the relationship between experimental factors and random variables. In this experiment, the influence factors are the detection distance, ambient light intensity and object reflectivity, and the random variable is the error of the TOF image. The significance level is the default value 0.05. The errors on the same pixel which is showed in Fig. 2 has been collected under different influence factors. Based on a hypothesis that there is no interaction between the three factors, objects distance from TOF camera can be easily set at 2m or 3m and its reflectivity can be set at 40% or 60%. And an LED lamp which can be set illumination to different power was used as ambient light. By calculation that are showed in Table I, reflectivity makes great influence on the results of TOF imaging, and ambient light takes the second place. Within the short range of measuring distance, our experiment has certain guiding significance. However, the essence of TOF imaging is still to make statistics on the number of returned photons which dictate the accuracy of TOF camera.

IV. Conclusion

In this work, we introduced an effective and simple method that can fundamentally identify the factors that affect the imaging accuracy of TOF camera. Based on three factors of measuring distance, objects reflectivity and ambient light intensity, we carried out the variance analysis of the collected data, and found that the interference of reflectivity of object is very large. However, there are many factors with interaction which affect the accuracy of TOF imaging. Therefore, further research needs to consider the effect of multiple factors acting simultaneously to eliminate the imaging error of TOF camera more effectively.

TABLE I
THE RESULTS OF ANOVA

Source	SS	df	MS	F	p
Distance	0.00156	1	0.00156	13.44	0.0008
ambient light	0.00941	1	0.00941	2.92	0.0955
reflectivity	0.00019	1	0.00019	0.47	0.4962
Error	0.01492	38	0.00322		
Total	0.01511	41			

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