Development of a mobile multi-spectral compound-eye camera TOMBO

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Abstract An imaging system TOMBO is based on a compound-eye camera whose image sensor is divided by small lenses. It has compact hardware and acquires multiple kinds of images at a time. In this research, we developed a mobile multi-spectral compound-eye TOMBO system capable of capturing subjects in a field environment. On the system, an embedded computer controls the TOMBO system. The developed system was mounted on an unmanned aerial vehicle and captured aerial images. We evaluated the images by a normalized difference vegetation index (NDVI) used in remote sensing and confirmed the usefulness of the proposed system.

Keywords: multi-spectral imaging, compound-eye, UAV

1. Introduction

A compound-eye imaging system TOMBO got inspiration from insect's eyes. It has compact hardware equipped on an image sensor divided by small lenses [1]. This system has two notable features. First, it is capable of collecting various types of image signals at once. Second, it is possible to design the optical system suitable for given purposes. For example, one can select different optical elements for each individual eye. As advantageous applications of TOMBO, we demonstrated three-dimensional shape measurement, super-resolution, and so on. However, most of these experiments were achieved in specific indoor environments, so that the scope of the applications was limited. In this study, aiming at extension of the usage range, we developed a mobile TOMBO system and clarified the usefulness. A prototype system uses an embedded computer, Raspberry Pi. We evaluated the basic performance. Then the system was mounted on an unmanned aerial vehicle (UAV) and we carried out an aerial observation experiment. We evaluated the aerial images by a normalized difference vegetation index, NDVI, used in remote sensing. Finally, we experimentally confirmed that extendibility of the usage range of the TOMBO system.

2. Prototype system

Considering the imaging characteristics of a compound-eye imaging system, we examined an effective usage method. In the TOMBO, nine lenses are evenly arranged on a plane as shown in Fig.1, so that the field of view (FOV) varies depending on the distance. Since parallax is large in the proximity field, three-dimensional measurement targeting the object distance and shape is possible. On the other hand, in the far field, FOV of the individual eyes are overlapped. The parallax becomes very small, and at infinity, all the eyes acquire the same object information. Figure 2 shows the calculation of the parallax amount when a trigonometric method is adopted for the individual eyes positioned in Fig.1. The baseline is 2.4mm, the pixelsize is 2.2μm, and the focal length is 1.5mm. For the parameters shown in Table 1, the distance longer than 1.6 m yields the parallax less than 1 pixel, and the two eyes observe almost the same FOV. In this study, we considered outdoor as the observation environment of the system. In the outdoors, the distance to the target object is long, so that 3D measurement using parallax is not suitable. On the other hand, when individual eyes are assigned to capture different signals of the same object, the alignment process for the captured images can be simplified. Therefore, we concluded that the optical system composed of different optical elements for the individual eyes is suitable for the prototype system. Figure 3 shows the structure of multi-spectral TOMBO (ms-TOMBO) in this study.

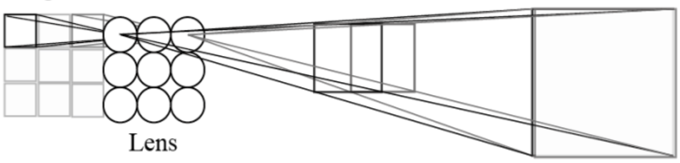

Fig. 1. Field of views of TOMBO system for different distance.

For the control computer of the prototype system, we chose Raspberry Pi 3 Model B [2], which is compact and easy to connect to the camera. The computer controls general purpose input/output ports and the ms-TOMBO. The system can be controlled by online operations through the input device and by offline operations using a start script. The system state during the flight was indicated by LED's to be monitored even from a distance. Table 1 shows the specifications of the prototype system.

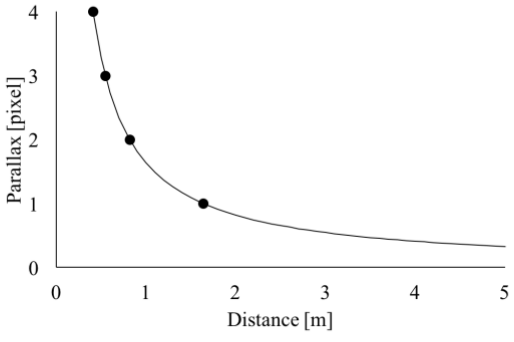

Fig. 2. Parallax value of the model in Fig.1.

Table 1. Specifications of the prototype system

Total weight / Energy consumption		45g / 2.4W
Compound eye	Model	ms-TOMBO
	Focal Length / F-number	1.5mm / 6
	Angle of View	50°
Computer	Model	Raspberry Pi 3 Model B
	CPU	ARM Cortex-A53 / 1.2GHz / ARMv8(64bit)
	Memory	1GB
	OS	Raspbian Stretch

3. Aerial observation experiment

We carried out an aerial observation experiment with the prototype system mounted on a UAV. For UAV mounting, gimbals were not used to reduce the weight. Instead, for vibration reduction, rubber was used to mount the ms-TOMBO on the UAV.

Figures 4 (a) and (b) show the picture of the flying UAV and an example of the captured image, respectively. The central wavelength of the bandpass filter for each individual eye is indicated on the image. Owing to a bad weather condition, the flying altitude ranged from 3m to 7m. As an example of image analysis, object discrimination by a normalized difference vegetation index NDVI (Normalized Difference Vegetation Index) [3] was performed. NDVI is defined as

$$NDVI = \frac{IR\text{-}R}{IR + R} \quad \cdots (1)$$

NDVI is an index for evaluating the activity of plants based on the ratio of the red channel and the near infrared channel considering the spectral reflection characteristics of plants. Since only a preliminary experiment was performed, NDVI was introduced to classify plants and non-plants. Pixel values of 650 nm channel were used for R in Eq.(1) and pixel values of 920 nm channel were for IR.

Figure 5 shows the calculated results. Here, the plant was indicated as green and the non-plant as red. Concrete blocks and grasslands were classified correctly, but some misclassification is found in cars and oil stoves due to slipping. The side glasses of the car were not correctly classified. This is caused by reflection of the glass and the surrounding plants as well as insufficient calibration between the wavelength channels. Through this experiment, it was confirmed that the application range of the prototype TOMBO system was expandable. Future issues include improvement of stabilization, dynamic control of the imaging capturing with the high sensitivity of the camera, and spectral reflectance measurement.

4. Conclusions

In this study, we have developed a mobile multi-spectral compound-eye camera TOMBO system that can be used in outdoor environments using Raspberry Pi 3B. Owing to the characteristics of the compound-eye optical system, multi-spectral imaging in which different wavelength channels are assigned to the individual eyes is suitable. We carried out an aerial observation using a UAV and demonstrated usefulness of the prototype system in object identification using the normalized difference vegetation index NDVI. As specific application targets of the mobile TOMBO system, precision agriculture and construction inspection are promising.

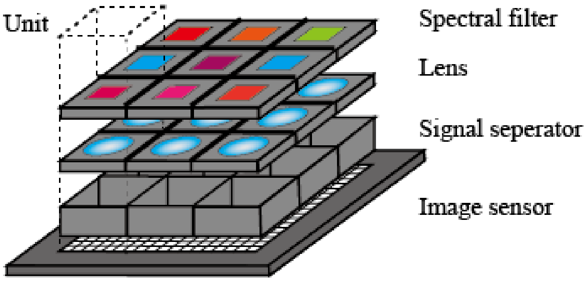

Fig. 3. Structure of multi-spectral TOMBO

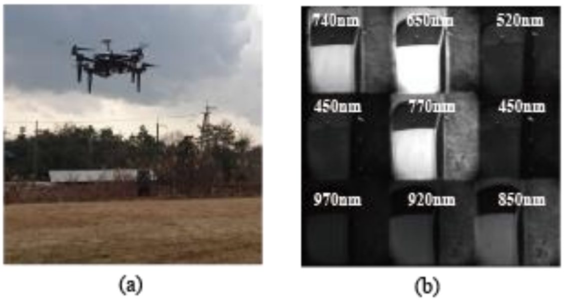

Fig. 4. Aerial shoot by the prototype system on UAV: (a) flying scene and (b) an aerial image

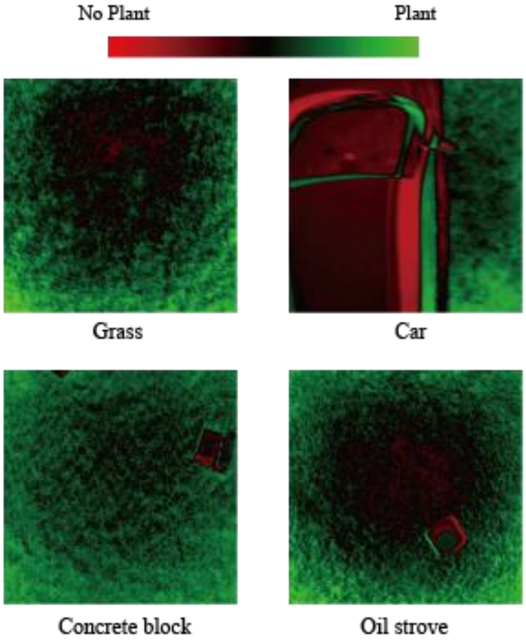

Fig. 5. NDVI for aerial images

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