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Micro-prism type single-lens 3D aircraft telescope system

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ABSTRACT

Based on the image payload on an Unmanned Aircraft System, this study utilizes a micro-prism array and single-lens remote camera to assess the feasibility of having two virtual cameras shoot terrain image pairs with inclined $\pm 10^{\circ}$. The software, LightTools, is applied for simulating and verifying the feasibility of the optical system. In comparison with traditional frame-type remote cameras, this study not only could acquire highly overlapped stereoscopic image pairs from different viewing angles, but could also increase the stereoscopic image pairs by two times. The system we propose obtains more stereoscopic digital terrain information than do traditional systems.

1. Introduction

Air-photo remote cameras are commonly utilized to obtain terrain and water images for people's livelihoods and science. Image payloads in airplanes present the function of stereoscopic observation that they could shoot the same terrain image pairs from various angles and produce a digital terrain model from the overlapped area of two-dimensional image pairs [1]. With the miniature electronic system and the mature development of communication technology, Unmanned Aerial Vehicles (UAV), which presents high resolution and added mobility, are applied to the surveys after disasters or for use with steep terrain. Nonetheless, unmanned aircrafts have less load capacity so that only light cameras can be equipped for remote [2].

Three types of remote stereoscopic image pairs are presently classified. With the aircraft moving at a uniform velocity, the first type is the Frame Type vertical photographs with fixed time intervals from which a stereoscopic image pair with a 60% overlapping rate can be acquired from two shots [3]. However, from this type, terrain dead space information is not easily obtained because of the small angle of the view and the vertical imaging. The second type are Three-Line-Scanner (TLS) images with Line Array CCD that images from three directions and can be shot in flight with an included 21° angle and a high overlapping rate [4,5]. Such a method is likely to affect the scanning precision because of jitter that results from flying and thus generates broken and blurred images. The third type is the Inclined Photography Technology with high parallax stereoscopic reproduction which has two or more Digital Single Lens Reflex Cameras (DSLR) horizontally shooting from both ends of the aircraft [6]. With the inclined angle about $\pm 30^{\circ}$ to the image, the stereoscopic image pairs are acquired by front and back positioning. Such a method requires two high-precision remote sensors that can cause a double load problem, increasing cost, consume more power, and require more calibrations for more cameras.

The proposed system is based on a refracting camera [7,8]. Lee et al. equipped a biprism in front of an ordinary camera and acquired one-shot-two-views [9]. This was accomplished by replacing the traditional stereoscopic imaging system with two cameras. Chen et al. proposed imaging technology with a micro-prism type single lens stereoscopic camera in 2008. In comparison with the biprism, a micro-prism allows reducing the volume and the weight of the system as well as improving the chromatic aberration of prisms [10].

In addition to the concept of one-shot-two-views in the micro-prism type single lens stereoscopic photography, a micro-prism array is equipped on the airborne frame type telecamera so that the optical characteristics of prisms could deflect the optical path and allow the vertical imaging system to be inclined to reduce the terrain dead space. Besides, obtaining terrain image pairs with one shot could largely increase the quantity of stereoscopic image pairs. The micro-prisms produced

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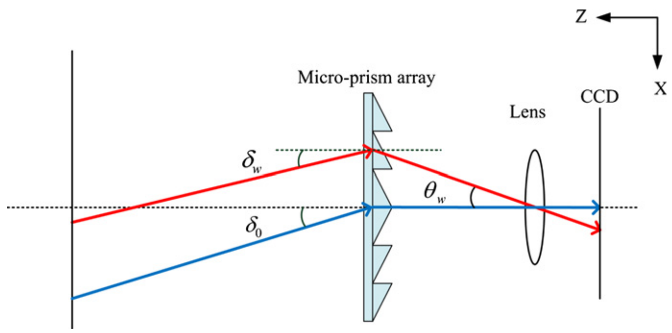

Fig. 1. Deflected field of view through micro-prism array.

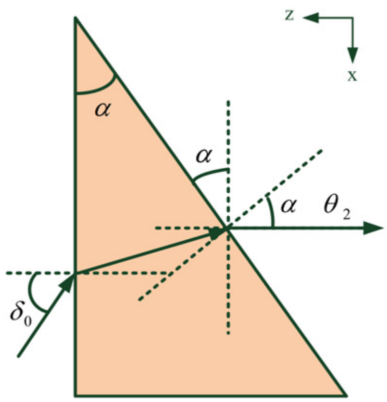

Fig. 2. Relationship between the deflection angle of the FOV and the field of view of half lens.

with micro-optic technology could effectively reduce the volume, the weight, and the cost to improve on the drawbacks of the above airborne imager.

2. Theory

This study designed a stereoscopic terrain imaging system with a micro-prism array equipped on an airborne camera. Fig. 1 shows the symmetrically rectangular prisms in the micro-prism structure so that the lower distribution of FOV of the prism could be theoretically analogized from the upper distribution. Through the micro-prism array, the entire field of view was defined as the deflection angle δ_0 and δ_w, the half angle of the view of lens θ_w, and the incidence of the micro-prism parallel with z-axis. The image width acquired from the half angle of view of the CCD camera could be calculated by δ_0 and δ_w.

The structure of the upper prism was magnified to discuss the relations between the deflection angle of FOV δ_0 and the half angle of the view of lens θ_w, as shown in Fig. 2. First, the clockwise direction included the angle between the light and the normal was defined as positive, and the counterclockwise one as negative. When the incident angle of the light was below the normal being δ_0, the projected light paralleled to z-axis and the included angle between the projected light and the second normal of the micro-prism equaled the vertex angle of the prism α. The equation of δ_0 and the vertex angle α is given by

$$\delta_o = \sin^{-1}\left(\sin\alpha\sqrt{n^2-\sin^2\alpha}-\cos\alpha\sin\alpha\right) \quad (1)$$

In Fig. 3, when the light entered from below the normal to the prism with the incident angle δ_w and the projected light entered

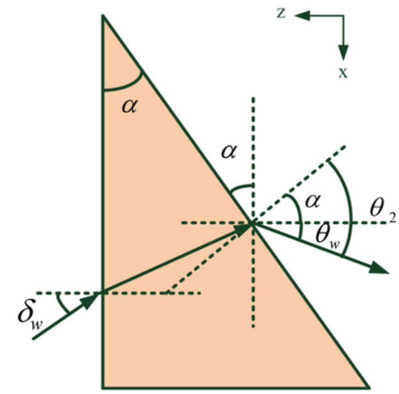

Fig. 3. Relationship between the deflection angle of the FOV and the field of view of half lens.

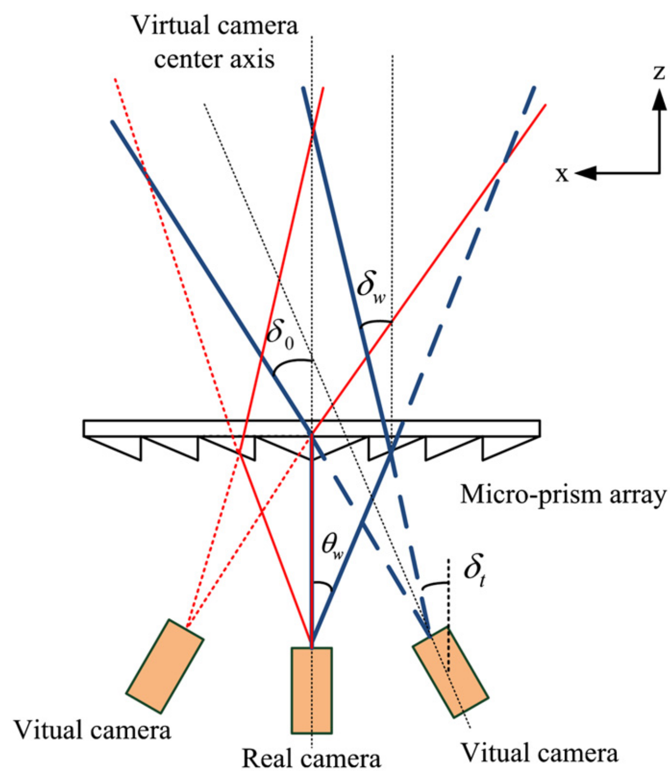

Fig. 4. Imaging with micro-prism array camera.

the half angle of view of the camera θ_w, the projected angle θ_2 equaled the sum of the vertex angle α and the half angle of view θ_w. The equation of δ_w and the half angle of view θ_w is given by

$$\delta_w = \sin^{-1}\left(\sin\alpha\sqrt{n^2-\sin^2(\alpha-\theta_w)}-\cos\alpha\sin(\alpha-\theta_w)\right) \quad (2)$$

When equipping the micro-prism array on the camera, the field of view would deflect with the characteristics of a prism so that the deflected field of view could be defined as the imaged FOV of two virtual cameras, as shown in Fig. 4. The two virtual cameras would incline to the same horizontal position with the left and the right fields of view almost overlapping, but they would separate with the increasing distance to the object. The inclined angle of the optical axis on z-axis of the virtual camera could be defined as δ_t, which could be determined by the