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Illumination compensation of microcamera image in monocentric multiscale foveated imaging system

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ABSTRACT

A novel imaging system based on monocentric multiscale design and foveated imaging is proposed to realize wide field of view (FOV) and high resolution dynamic gaze of the moving target. Different from the existing monocentric multiscale cameras, the individual microcamera of the proposed imaging system relays a relatively large portion of the overall intermediate image. The proposed imaging system has many advantages, but the illumination of the microcamera image is nonuniform. The edge illumination of the microcamera image is low that makes it difficult to the subsequent image data processing. We analyze the illumination of the image theoretically and propose to use the relative illumination factor to compensate the low illumination region in corresponding fields. Finally, a specific microcamera is designed by using ZEMAX software and the illumination of the microcamera image is optimized by the proposed method, realizing the uniform illumination of the image.

1. Introduction

High resolution, wide field of view (FOV) is highly desirable in many applications such as teleconferencing, surveillance, and robot navigation [1–4]. However, imagers that simultaneously combine the wide field of view and high angular resolution present a difficult challenge in optical system design [5]. A considerable amount of research has been dedicated to the exploration and development of wide FOV and high resolution imaging system [6–10]. Among them, the monocentric multiscale lens design is considered to be one of the most prominent wide FOV and high resolution imaging method [10–12]. Despite its many advantages, monocentric multiscale lens suffers from the inherent drawbacks of having high density microcameras and big volume of the system [13]. There are too many microcameras forming the secondary system that makes them difficult in assembling and causes big sampling data, inevitably leading to the difficulty of the follow-up image processing and transmission. In addition, the monocentric multiscale imaging system cannot gaze the moving target dynamically.

In order to simultaneously realize wide FOV and high resolution dynamic gaze of the moving target, we propose the monocentric multiscale foveated (MMF) imaging system based on monocentric multiscale lens design [10–12] and foveated imaging [14–16]. The MMF imaging system consists of a primary monocentric objective lens and 3 × 3 secondary subimaging systems. Each secondary subimaging system consists of a microcamera and a foveated imager and they share the same monocentric objective lens. The system uses 3 × 3 microcameras to relay the intermediate image formed by the monocentric

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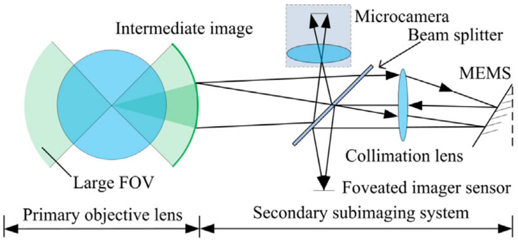

Fig. 1. Schematic design of the proposed MMF imaging system.

objective lens, avoiding the high density microcameras. Thus, each individual microcamera relays a relatively large portion of the overall intermediate image produced by the monocentric objective lens. However, large portion of the intermediate image relayed by the microcamera will bring the nonuniform illumination to the microcamera image. The edge illumination of the microcamera image is low that makes it difficult to the subsequent image data processing. A lot of effort has been made to achieve the illumination uniformity. By introducing negative distortion, the illumination may be expected to be more uniform from the center to the edge of the field [17]. But distortion may cause positional error of the moving target in our proposed imaging system. Inserting an lens array into a common focal system, the uniformity of the illumination can evidently be improved [18]. An effective method is to insert a neutral density filter with a radially varying transmission into the optical system [19]. The filter has a transmission profile which provides a fairly precise match for the image illumination fall-off. Also by adding a stop [20] or a central obscuration [21] into the optical path to reduce the on-axis rays more than the off-axis rays can even the illumination of the image. However, all these methods are difficult and they need to employ sophisticated optical components into the imaging system.

In this paper, we present the MMF imaging system and propose to use the relative illumination factor to compensate the low illumination region in corresponding fields. We have organized this paper as follows. In Section 2, the MMF imaging system concept is presented and the nonuniform illumination of microcamera image is analyzed theoretically. Section 3 is devoted to optimize the illumination of the secondary image acquired by the microcamera. Finally, we summarize the main achievements in Section 4.

2. Analysis of illumination of the microcamera image in mmf imaging system

2.1. MMF imaging system concept

The MMF imaging system consists of a primary monocentric objective lens and 3×3 secondary subimaging systems. Each secondary subimaging system consists of a microcamera and a foveated imager and they share the same monocentric objective lens. The system uses 3×3 microcameras to relay the intermediate image produced by the monocentric objective lens. Thus the entire visual field is divided into 3×3 sub-FOVs, and then all the secondary images acquired by the microcameras synthesize a mosaic image, which achieves the large FOV image. Meanwhile, the foveated imager is designed in each sub-FOV to achieve the high resolution dynamic gaze of the moving target. Fig. 1 shows the schematic design of the MMF imaging system with one secondary subimaging system. As shown in Fig. 1, a beam splitter behind the spherical intermediate image splits the rays coming from one point of the intermediate image into two beam segments by 50/50 and separates the optic paths: one path, reflected to the microcamera; the other path, straight forward to the foveated imager. A collimation lens collects the light transmitted through the beam splitter to the two-axis micro-electro-mechanical system (MEMS) mirror. By tilting the MEMS mirror instantaneously toward the direction of the moving target, which is driven by fovea tracking algorithms, rays of light reflected by the MEMS mirror are redirected toward the optical axis. The same collimation lens collects the rays of light reflected by the MEMS mirror and forms the image of the target. Thus, the foveated imager is capable of sweeping the foveated FOV across the microcamera FOV as shown in Fig. 1. In the meantime, the microcamera is placed on the reflected path of the beam splitter to form the image of the sub-FOV of the entire visual field.

The foveated imager mimics the fovea pit of the eye and provides a long focal length and a narrow FOV. The foveated imager is capable of sweeping the foveated FOV across the microcamera FOV (sub-FOV) by tilting the MEMS mirror, which mimics the human eye movements. Therefore, the foveated imager has the dynamic capability for high resolution target tracking. The microcamera mimics the peripheral vision of the eye and captures an extended field with relatively low resolution. It provides the peripheral context for stimulus detection. In order to provide sufficient information for post image mosaicking, a small overlapping FOV is needed between adjacent sub-FOVs.

2.2. Analysis of illumination of the microcamera image

In the monocentric multiscale imaging system, there are lots of microcameras to relay the spherical intermediate image produced by the primary monocentric objective lens, e.g., the completed camera AWARE-2 involves 98 microcameras and AWARE-10 involves 382 microcameras. Hence, an individual microcamera of the AWARE imagers relays a small portion of the