Available online at www.sciencedirect.com
SCIENCE DIRECT
Sensors and Actuators A 128 (2006) 191–196
SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

A thin camera with a zoom function using reflective optics

Hideyuki Kinoshita *, Kazunori Hoshino, Kiyoshi Matsumoto, Isao Shimoyama

Department of Mechano-Informatics, Graduate School of information Science and Technology, The University of Tokyo, Japan

Received 1 March 2005; received in revised form 19 December 2005; accepted 29 December 2005
Available online 20 February 2006

Abstract

We propose a camera that can maintain its thin dimension even when it utilizes a lens with a large focal length to zoom in. Large focal length have made the structure of a conventional camera thick. In this paper, we show how *reflective optics* prevents a camera from requiring significant thickness. Reflective optics is an inclusive term for optical systems consisting of mirror reflectors or a combination of lenses and mirrors. To demonstrate the concept, we fabricated a double-focus lens. Since this lens has a wide-angle lens inside and a telescopic lens outside, two views from different focal lengths can be obtained by deciding which part of the lens is to be used. We fabricated a micro-mirror structure that has flexible hinges and is actuated by external magnetic fields. The mirror that reflects light through the outside lens also takes the role of a shutter, by blocking light passing through the inside lens when the camera is utilizing the outside lens. By shifting the mirror, the camera can allow light to pass through the inside lens. Thus, the view with the double-focus is selected by actuating the mirror. We demonstrated switching between the two views with our prototype camera.

Keywords: Reflective optics; Camera; Micro-mirror; Out-of-plane; Double-focus lens

1. Introduction

Optical devices offering functions of zooming or varying focuses with less moving parts for miniature cameras have been developed. For example, a liquid lens controlled by electrowetting has already realized a variable focus with no lens displacement [1]. This report describes another approach to avoid lens movements in a zoom camera. In implementing optical zoom-in, it is generally required to place the lens at a distance from the photo sensor, because a lens for zooming-in has a larger focal length. We applied reflective optics to our thin camera. The basic idea of reflective optics was invented in the 1600s and has been applied in astronomical telescopes for years. These days, reflective optics is attracting attention from the camera industry as a means of achieving long light paths in thin products. To implement this idea, we have fabricated a shutter composed of a micro-mirror actuated by magnetic fields.

Recently, techniques for actuating micro-mirrors have been developed, particularly for space scanners and optical switches [2]. Two-dimensional (2D) scanners utilizing micro-mirrors have previously been reported [3]. Electrostatic comb actuators drive these micro-mirrors, while optical choppers and attenuators are used to open and close the shutter and control the light path [4]. In these applications, the mirrors and shutters require very small displacements. Therefore, it was suitable to use comb actuators, which have small displacements.

In our camera proposed here, the magnification depends on whether the reflective optics are used; i.e., on zooming out or zooming in. This requires a large, movable mirror with large displacements, because the lens's diameter is more than 1 mm. We have used out-of-plane techniques to the mirror's fabrication process. These techniques are applied in microstructures assembly and mostly used flexible parts or hinges [5]. A standing cantilever and a vertical-planar spiral conductor were fabricated by applying magnetic fields [6]. Another report describes how the orders of a structure's lift-up motions induced by an external magnetic field, resulting in many 3D tetrahedron structures [7]. In another work, micro-mirrors connected to a substrate by hinges were rotated around the hinges by melting photoresist, and they were then fixed by a locking mechanism [8]. Thus, 3D micro-optical structures have been implemented. Our mirror with no locking mechanism is movable in order to adapt to different requirements.

* Corresponding author at: Engineering Bids.8 Rm437, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan. Tel.: +81 3 5841 6318; fax: +81 3 3818 0835.
E-mail address: kinoshita@leopard.t.u-tokyo.ac.jp (H. Kinoshita).

0924-4247/$ – see front matter
doi:10.1016/j.sna.2005.12.046

In the current work, we have demonstrated not only using reflective optics but also switching between two different views by actuating the shutter with micro-mirrors and using a double-focus lens [10].

2. Camera's principle and structure

Fig. 1(a) illustrates reflective optics. The original focal length of a lens is denoted as F1. We employ two mirrors, one ring-shaped, and the other circular. Light passing through the lens is reflected twice by these mirrors and focused by reflective optics onto a photo sensor at a position closer than the original focal length, F1. In this case the central part of the lens is not used. Then a different curvature is applied in the inside part. The designed focal length of the inside lens is F2 (Fig. 1(b)). The mirror shifts from the central part, the inside lens is used, and an image is obtained. The lens thus becomes a double-focus lens. When the mirror returns to the central part, the outside lens can be used (Fig. 1(c)). As a result of utilizing reflective optics for the zoom function, the distance between the lens and the photo sensor does not change.

Fig. 2 shows the structure of our camera, which consists of four main components: the lens, a charge-coupled device (CCD), a ring-shaped mirror, and a shutter that has a mirror. The lens is on a glass substrate, with the shutter attached to the reverse side. The ring-shaped mirror is fabricated on another glass substrate and placed on the CCD. The lens is a combination of two lenses, where the inside one is a wide-angle lens and the outside lens is a telescopic (narrow-angle) lens. The focal length of the outside lens is about three times greater than that of the inside lens. The shutter under the lens has a movable mirror.

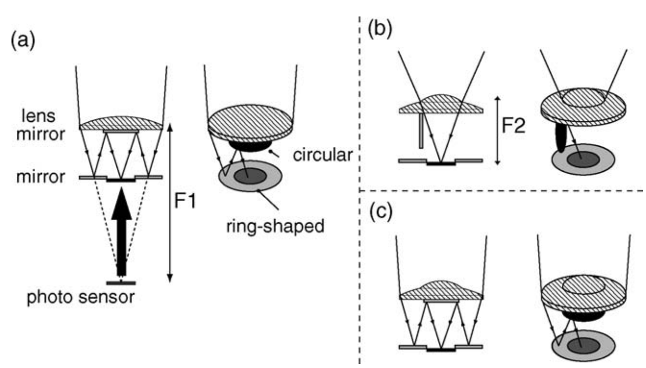

Fig. 1. (a) Light is reflected by two mirrors and focuses onto a photo sensor. (b) A different curvature is applied in the inside part. The outside lens becomes a telescopic lens and the inside lens does wide-angle lens. Then mirror shifts from the central part. (c) When the mirror return to the central part, the outside lens is used and zoom function is realized by reflective optics.

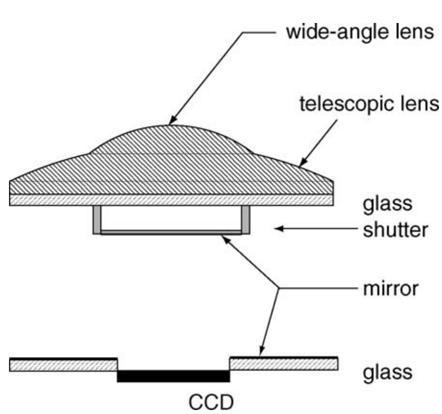

Fig. 2. Structure of the camera.

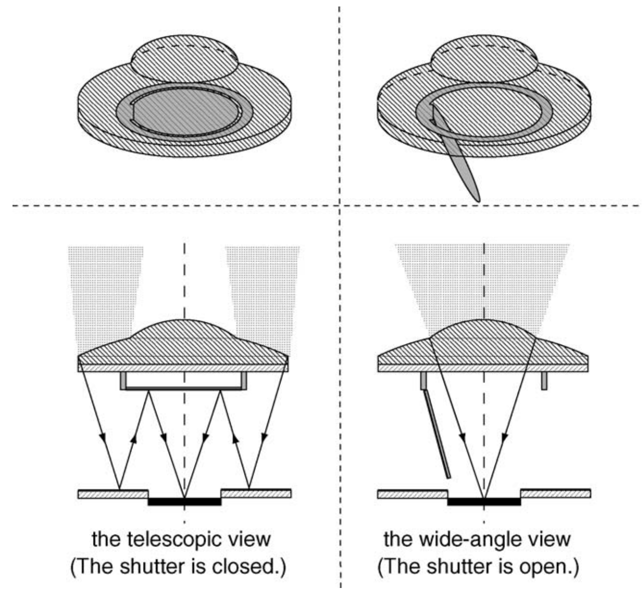

Fig. 3. Principle of switching between the two views.

The principle for switching between two views without changing the camera's structure is illustrated in Fig. 3. For a telescopic view, the shutter is closed to block the light through the inside lens, and the light through the outside lens is reflected twice by the two mirrors (i.e., the ring-shaped mirror located above the CCD, and the circular mirror on the shutter) to generate an image on the CCD. As a result of being reflected by the two mirrors, the light can follow a long path in the same space. For a wide-angle view, the shutter is opened, and the light through the inside wide-angle lens is focused into an image on the CCD. The outside telescopic lens does not work in this case. Thus, by opening and closing the shutter, two different views can be obtained. We use a soft magnetic material (Ni) to form the mirror of the shutter. Its opening and closing can then be controlled by directing external magnetic fields. This utilizes the simple phenomenon that when a thin magnetic plate is set on a permanent magnet, the plate stands up on it in the direction of the magnetic field [9].

In this way, the distance between the lens and the CCD is fixed by using reflective optics, and the camera can change views while keeping a thin structure. In theory, the double reflection of the light thorough the outside lens does not affect the image size or direction. Therefore, the image is the same as the image that would be obtained by a CCD located at a distance equal to the original focal length of the lens.

The ratio of the focal lengths of the inside and outside lenses determines the magnification and the precise design specification of our camera, such as the size of the mirror, the arrangement