Development of Switchable LF Camera for Capturing 2D/3D Movie

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ABSTRACT

We developed a fast switchable light field (LF) camera which can simultaneously capture the 2D and 3D videos based on implemented switchable polarization-dependent micro-lens array (MLA). The proposed LF camera system was demonstrated that can simultaneously capture the 2D and 3D video even in high speed driving over 1000 fps.

1. INTRODUCTION

Since the invention of image sensors, digital cameras have been widely utilized for capturing images. According to the improvement of image sensor and image processing technology, it is possible to capture high quality image by using the digital camera. The people want to use a digital camera to capture not only high quality two-dimensional (2D) images, but also three-dimensional (3D) information of object. However, digital camera system can only provide two-dimensional (2D) information, not a 3D information of the real object.

To resolve these problem, the Light-Field (LF) camera has been developed as a way to obtain 3D information of object by utilizing digital camera with micro-lens array (MLA) [1,2]. The LF camera is a technology that can obtain not only intensity, but also LF information of incident light by placing MLA in front of the image sensor. By utilizing the captured elemental image array, the LF camera can reconstruct the directional view images with full parallax information and digitally refocusing images with different depth plane [3]. However, the LF camera have a disadvantage that the resolution of reconstructed images is degraded in proportion to the density of utilized micro-lens array. To people who familiar with high quality image of digital camera, the low resolution of reconstructed images are a fatal drawback for LF camera even though LF camera have many useful functions [4]. To improve the resolution problems, the LF camera should be able to reconstruct the directional view and digital refocusing images while retaining the capturing function of conventional high quality 2D image.

In this paper, we proposed a fast switchable LF camera using polarization-dependent MLA to simultaneously capture the 2D and 3D videos. Because of the fast-switchable property of polarization-dependent MLA, the proposed LF camera can take the 3D videos which can reconstruct the directional view and digital refocusing images while taking the high resolution 2D videos obtained from conventional digital camera. We confirmed that the proposed LF camera system can be applied not only to the video capturing speed of 50 fps, but also to the faster video capturing speed of 1000 fps.

2. Principle and schematics diagram of our proposed LF camera

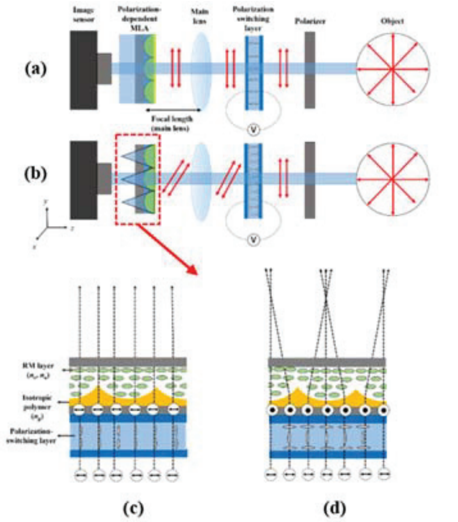

Fig. 1. Operational principle and schematics diagram of our LF camera system: (a), (b) schematics diagram of our LF camera system as 2D and 3D mode, respectively. (c), (d) the operational principle with polarization-dependent MLA according to field on and field off state, respectively.

Figure 1 shows a principle and schematics diagram of proposed LF camera system using polarization-dependent MLA. We set the distance between the main lens for imaging of the object and the polarization-dependent MLA to be the focal length of main lens. To control the operation of polarization-dependent MLA, a polarizer and a polarization switching layer are installed as shown in Figs. 1(c) and 1(d). Fig. 1(c) shows operational principle of our proposed LF camera operating in 2D mode, where the polarized incident light reflected from the object pass the field on states polarization switching layer without changing the polarization state. About the linearly polarized incident light which parallel with y-axis, the reactive mesogen (RM) has an ordinary refractive index n_o which is same with refractive index n_p of isotropic polymer. As a result, polarization-dependent MLA operates as defocusing mode and 2D image arrives in image sensor, as shown in Fig. 1(a). However, in the 3D mode, when the polarization state of the incident light was changed to the orthogonal polarization state which parallel with x-axis by polarization switching layer, RM has an extra refractive index as n_e which is higher than n_p. As a result, polarization-dependent MLA can be operated as focusing mode to obtain the 3D LF elemental image array, as shown in Figs. 1(b) and 1(d) [5].

3. Fabrication of polarization-dependent MLA

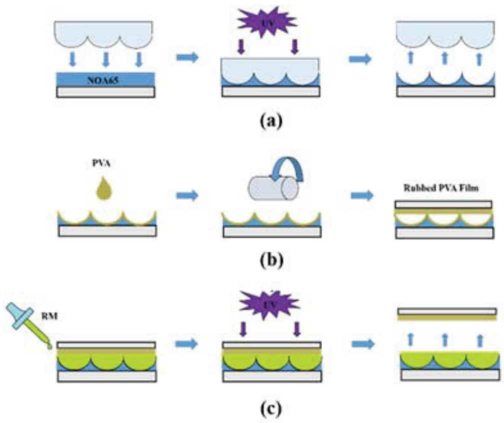

Fig. 2. Fabrication process of polarization-dependent MLA: (a) imprinting process, (b) rubbing process for top-down alignment effect, and (c) RM lamination and polymerization process.

Figure 2 shows a schematic diagram of the fabrication process to implement the proposed polarization dependent-MLA. To implement the polarization-dependent MLA, we utilized the square shape microlens array template which have a pitch of 100 μm and a focal length of 800 μm, respectively. As shown in Fig. 2(a), the reversed shape of the utilized microlens array template is formed through imprinting process by using the ultra violet (UV) curable polymer NOA81 (n_p = 1.51, Norland Products Inc.) which is transparent and optically isotropic in the visible light region. In order to align the RM molecules (RMM727, n_o=1.51, n_e=1.68, Merck) in one direction, an alignment layer have to be formed on the reversed shape template. The polynivyl alcohol (PVA) solution for utilizing alignment layer was coated on the UV-ozone treated template and thermally cured at 90°C for 30 minutes. To confirm alignment properties, the PVA layer was rubbed to obtain the well-aligned RM molecules, as shown in Fig. 2b. To induce the top-down alignment effect, we additionally used rubbed PVA layer substrate, as shown in the Fig. 2b. The RM layer was formed between the reversed shape of microlens array and top PVA film through a lamination process. When the RM layer formed between the substrates is polymerized through UV exposure, the well-aligned RM layer is obtained along the rubbed direction of PVA layer. Finally, we implemented the polarization dependent microlens array, as shown in Fig. 2c.

4. Optical property of polarization-dependent MLA

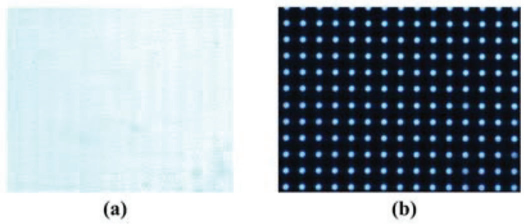

Fig. 3. Polarizing optical microscope images of polarization-dependent MLA for (a) 2D and (b) 3D mode.

Figure 3 shows the optical microscope images of our implemented polarization-dependent MLA for operating with 2D and 3D mode, respectively. When the linearly polarized light with x-axis enters the polarization dependent MLA, the polarization-dependent MLA operated as a transparent substrate as shown in Figs. 1(a) and 3(a). When the linearly polarized light with y-axis enters the polarization-dependent MLA, it can be obviously seen that it is focused with each microlens as shown in Figs. 1(b) and 3(b).

4. Experimental results and discussion.

Fig. 4(a) shows the high resolution 2D image which was captured with polarization-dependent MLA in 2D mode, where the 2D image was focused in a behind object showing the blurred object in near depth. Fig. 4(b) shows the elemental image array which was captured with the polarization-dependent MLA in a 3D mode. We can confirm that the elemental image array clearly obtained through the each MLA with its LF ray information. Fig. 4(c) shows the experimental results after digital-depth refocusing process using the captured elemental image array from the Fig. 4(b). The resolution of each refocusing image is 94 x 103 pixels. We can confirm that our proposed LF camera was possible to create a focused image on a virtual synthetic image plane existing in a depth range. To capture the 2D/3D videos, the response time of polarization-switching layer was measured about 510μs. By switching applied voltage as 2D/3D signal, 2D/3D images are simultaneously captured with video frame rate (50fps).

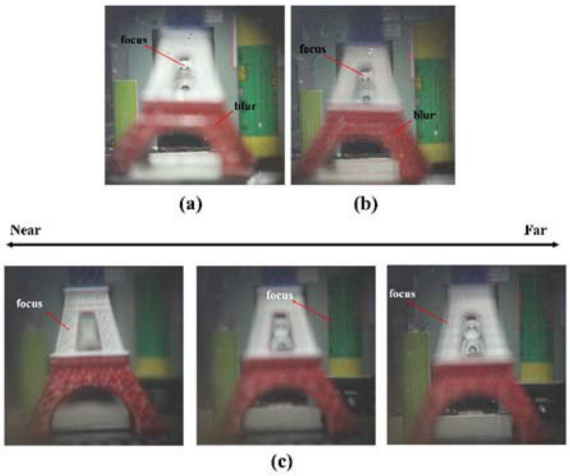

Fig. 4. The reconstructed images with proposed LF camera system: (a) the captured 2D image in 2D mode, (b) the captured elemental image arrays in 3D mode and (c) the digitally refocusing images obtained from elemental image arrays.

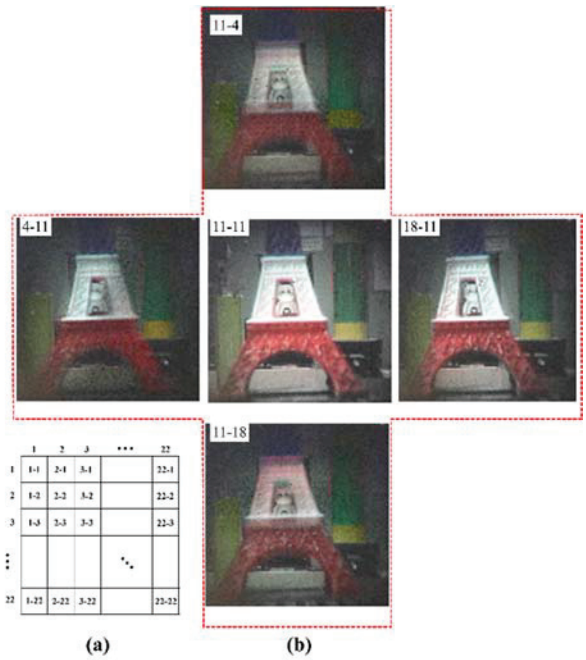

Fig. 5. The reconstructed directional view images obtained from elemental image arrays: (a) the definition for naming the number according to the position of directional view, (b) the directional view images obtained from elemental image arrays.

Figure 5(a) shows the numbers of each reconstructed directional view image which defined according to the position of reconstructed directional view. The resolution of each reconstructed directional view image is 94 x 103 pixels and numbers of total reconstructed directional view image are the 22(horizontal) x 22(vertical). The vertical and horizontal direction parallaxes can be confirmed from 5 reconstructed directional view images, as shown in Fig. 5(b). First, the reconstruction capability of horizontal direction parallax can be confirmed through the three reconstructed images such as 4-11, 11-11, and 18-11. We demonstrated that our proposed LF camera can capture and reconstruct the horizontal parallax information. Next, the reconstruction capability of vertical direction parallax can be confirmed through the three reconstructed images such as 11-4, 11-11, and 11-18, as shown in Fig, 5(b). We also demonstrated that our proposed LF camera can capture and reconstruct the vertical parallax information. From these obtained reconstructed results, we can confirm that our proposed LF camera can capture and reconstruct about the full parallax information in all directions.

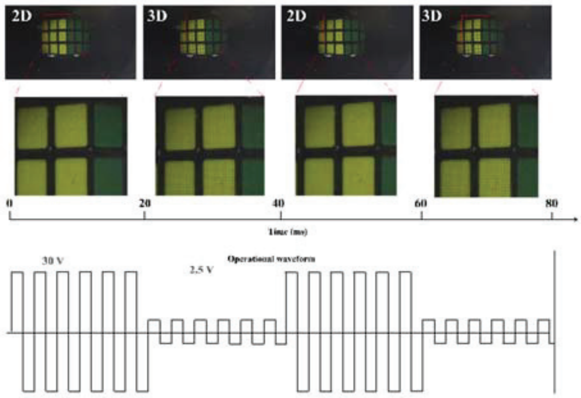

Fig. 6. The extracted six frame images from simultaneously 2D/3D video capturing using our proposed LF camera with polarization-dependent MLA.

We applied an operating waveform with 50 fps to polarization-switching layer, and obtained a video for rotating object located in front of the other fixed cube shape object. If the switching speed of the proposed polarization-dependent MLA is slower than the video capturing speed of 50 fps, the sequence of the extracted 2D and 3D images per each frame would be extracted with irregular order. On the other hand, if the switching speed of the proposed polarization-dependent MLA matched with the video capturing speed of 50 fps, the sequence of the extracted 2D and 3D images per each frame would be extracted alternate with each other. In the Fig. 6, we show the operating waveform and six consecutive images among the whole extracted frame images using the simultaneously captured video. When the video capturing speed of LF camera is 50 fps and the operating waveform is lower image of Fig. 6, it can be seen that the 2D and 3D images are extracted alternately as shown in the upper consecutive image of Fig. 6

5. Conclusion

The LF camera system can reconstruct the directional view and digital refocusing images with a wide DOF by utilizing the obtained one elemental image unlike the conventional 2D digital camera. From these advanced function of LF camera, the LF camera have been widely researched to resolve the focusing problems in the conventional 2D digital camera. We proposed a LF camera with fast switchable polarization-dependent MLA to obtain the simultaneously capturing function of 2D and 3D videos. The implemented polarization-dependent MLA could be actively operated between the 2D and 3D mode as well as obtaining an ideal refractive index profile for perfect lens. Therefore, proposed LF camera can reconstruct the directional view and digital refocusing images as well as retaining the capturing function of high resolution 2D image obtained from conventional digital camera. We confirmed that the proposed LF camera system can be applied not only to the video capturing speed of 50 fps, but also to the faster video capturing speed of 2000 fps. We demonstrate that the proposed LF camera can reconstruct the directional view and digital refocusing images by utilizing extracted elemental image from the captured videos. Additionally, the compact LF camera module which was integrated with polarization-dependent lens and polarization switching layer, will be carried out in our future work about LF camera. Finally, we expect that our advanced LF camera will be widely utilized in the microscope and camera imaging applications.

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