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Rectification of distorted elemental image array using four markers in three-dimensional integral imaging

Hyeonah Jeong[1] and Hoon Yoo[2]*
[1]*Department of Computer Science, SangMyung University, Korea.*
[2]*Full Professor, Department of Electronics SangMyung University, Korea.*
**Corresponding author*

Abstract

This paper proposes a method for accurate elemental image array extraction and preprocessing in three-dimensional integral imaging. We introduce the effect of error in the existing marker method on reconstructed images and we propose rectification and automatic extraction methods of an elemental image array with minimum markers. In this paper, the proposed method provides a low-cost calculation method. Also we analyze the effects of distortion and noise on the image reconstruction process. Thus the proposed method can obtain more accurate elemental image array than the existing method using minimum markers. Experiments show that the proposed method has better performance than the existing methods.

Keywords: Three-dimensional integral imaging, elemental image array, preprocessing method, lens array

INTRODUCTION

Integral imaging was first proposed by G. Lippmann as one of the techniques for recording and reconstructing 3D objects [1]. This technique consists of a pickup process of recording 3D object information into an elemental image array using a lens array, and a process of reconstructing and displaying the 3D image by integrating using the same lens array. The integral imaging system can be displayed in a volumetric form and there is no visual irritation even if it is viewed for a long time. In addition, it does not require any special glasses, and provides a continuous view point in the vertical and horizontal directions within a certain viewing angle. It also has the advantage of real-time color implementation. Using these features, integral imaging technique has been used for many studies [2-6].

Noise and distortion are likely to occur in the elemental image due to external factors in the pickup process through the optical device. When recording optically 3D object, it is affected by various external influences such as misalignment between lens array and image detector, angle of illumination [7, 8]. Since such errors will greatly affect the display process later, it is very important to remove noise and distortion to improve the image quality and display correctly. Several methods have already been proposed as preprocessing techniques for correcting distortion and extracting high-quality elemental image array [9-13]. There is a method for calculating a rotational error angle of a lens array using a Hough transform [9]. In addition, an elemental image array extraction method using a lens array lattice pattern and a projective transform method of the lattice edges also have been proposed [10, 11]. And, a method of calibrating using a marker attached to the lens array surface has also been studied [12].

The existing approaches are problematic when the lattice pattern is not visible by the experimental environment or when using lens array of different shapes as shown in Fig. 1. Also, the edge of the object may be misinterpreted as a lattice pattern [7-11]. On the other hand, the method using surface markers is easy to extract and less error because the distinction between the image and the marker is clear. In addition, it can be used irrespective of the shape of the lens array, and it is possible to automatically extract an elemental image array of a good image quality as a whole [12]. In the existing method using markers, 9 markers were used because it was predicted that the accuracy of the correction formula would increase as the number of markers increased. This, however, affects 3D image reconstruction by the middle marker among 9 markers. Also, the rectification equation obtained by the centroid point of the marker is calculated with the centroid point adjusted by many markers, not the actual centroid point. This interferes with obtaining pixel values at the correct position during the image rectification process.

In this paper, we propose a preprocessing method for automatic extraction of elemental image array during the pickup process and improvement of image quality in the reconstruction process. We introduce a simple method with similar performance but using minimal markers and confirm the effect of the middle marker on the reconstructed image through various experiments.

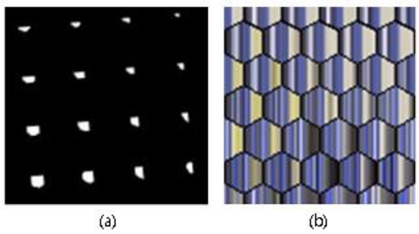

Figure. 1: Examples of elemental image array in which edge detection is difficult

The Existing Method

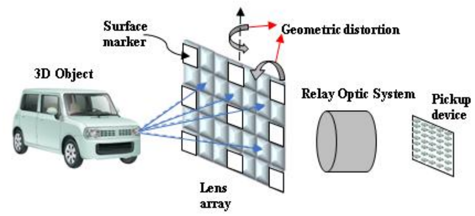

Figure 2: Pickup system of the existing method

Figure 2 shows the pickup system of the existing preprocessing method using markers [12, 14]. This method attaches 9 markers to the surface of the lens array, and then uses the information of the marker to obtain the transform coefficient and correct the distortion. Compared with other preprocessing techniques, there is no limitation of image and it is possible to easily extract elemental image array. The markers can be designed by the user in accordance with the size, position, and color, and it is easy to distinguish the marker from the image by using the intensity of light or color. In this way, the marker is designed to easily extract the correction formula of the elemental image array, and information for correcting the distortion (skew, rotation, translation) is obtained through the lens array size and the pixel value.

To obtain the rectification information, the centroid point is calculated through the markers found in image. The centroid point is the most important parameter when calculating the degree of distortion. This is because distortion can be corrected by obtaining a transform coefficient at each centroid point. The transform coefficient obtained by using multiple markers can easily rectify the elemental image array by calculating the degree of distortion through linear transform and least squares [15].

In this method, 9 markers were used because it was predicted that the accuracy of the rectification equation would increase as the number of markers increased. However, the equation obtained by the centroid point is calculated with the centroid point adjusted by many markers rather than the actual centroid point. This interferes with obtaining pixel values at the correct position during the image rectification process. In addition, the middle marker among the nine markers affects after reconstruction, resulting in a problem that the color PSNR (Peak Signal Noise Ratio) value is measured low.

The Proposed Method

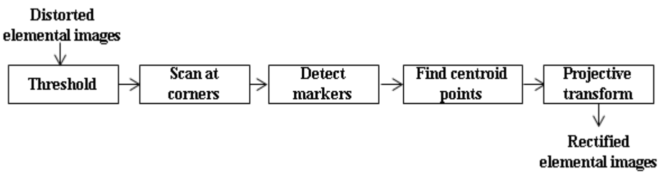

Figure 3: Flowchart of the proposed method

Figure 3 shows a flowchart of the proposed method. First, we use 4 markers instead of 9, unlike the existing method. After attaching the markers to the lens array, a two-dimensional elemental image array is obtained through a pickup process. The pickup color image is thresholded to easily extract the markers. The centroid points and size information of the markers are obtained through the thresholded image, and the image is rectified by projective transform. Using the proposed preprocessing technique, it is possible to automatically extract elemental images and improve image quality.

1. Comparison with the existing method

Equation (1) is the transform coefficient calculated by the existing method and Equation (2) represents the transform coefficient of the proposed method. Table 1 compares the centroid points of the markers with the centroid points of the four closest markers in the corners calculated through the respective transform coefficients to analyze the effect of the transform coefficients. It can be seen that the coefficient of the existing method calculated by the least squares method is different from the position where the centroid point position is actually searched, and a slightly misaligned position is calculated at the time of rectification.

$$T_{9tag}{}^{-1} = \begin{bmatrix} 1.0584 \times 10^{0} & -5.8037 \times 10^{-2} & 1.0607 \times 10^{2} \\ -6.0695 \times 10^{-5} & 9.9505 \times 10^{-1} & 1.0999 \times 10^{2} \\ -8.9346 \times 10^{-5} & -9.1472 \times 10^{-5} & 1.0000 \times 10^{0} \end{bmatrix} \quad (1)$$

$$T_{4tag}{}^{-1} = \begin{bmatrix} 1.0587 \times 10^{0} & -5.8713 \times 10^{-4} & 1.0652 \times 10^{2} \\ -1.0034 \times 10^{-5} & 9.9411 \times 10^{-1} & 1.0960 \times 10^{2} \\ -1.0544 \times 10^{-5} & -9.2656 \times 10^{-5} & 1.0000 \times 10^{0} \end{bmatrix} \quad (2)$$

The centroid point is an important parameter for calculating the degree of distortion. However, it is difficult to find the exact pixel position when rectifying the image using the existing method. It can be seen that the 9 markers interfere with the correct rectification of the elemental image array. In addition, when the image reconstructed through the CIIR method, the image reconstructed at a close distance is affected by the markers [16]. When the undistorted image picked up by the computer and the image rectified by the existing method are reconstructed and compared with each other, the color PSNR value is measured to be low due to the influence of the center marker while covering one elemental image.

The proposed method reduces the number of markers to 4 in order to improve the image quality of the elemental image and accurately calculate the transform coefficient. Through this method, we can derive a simple and accurate calculation formula and extract the elemental image array with better performance.

Table 1: Comparison of centroid points

row, col	Position	$T_{9tag}{}^{-1}$	$T_{4tag}{}^{-1}$
0th tag	158.02, 155.21	158.18, 155.14	158.02, 155.21
1st tag	158.01, 1140.98	157.74, 1140.79	158.01, 1140.98
2nd tag	1186.00, 1188.89	1186.19, 1188.76	1186.00, 1188.89
3rd tag	1186.00, 110.03	1185.73, 109.75	1186.00, 110.03

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2. Elemental image array rectification

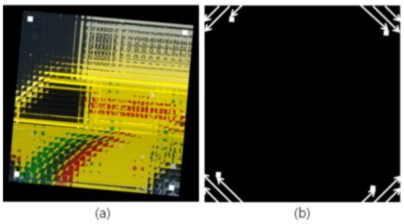

Figure 4: Marker scanning method of distorted image

In order to easily separate the marker from the image during rectification process, the marker is designed considering the intensity of color or light. The elemental image array is thresholded to obtain initial information of the markers. The thresholded image is scanned to obtain maker position and size information. For a simple and efficient maker search, we start scanning from each corner of the image as shown in Fig. 4. Within a certain range of distortions, selecting the marker closest to each corner is the simplest way to recognize the marker's position. 4 markers are extracted using this scanning method.

We calculate each centroid points using pixel information obtained by scanning all the corners. It is very important to find the centroid point of the marker because it needs to extract the information of the error through the centroid point and size of the markers. In order to take advantage of the marker method, it is necessary to find the precise centroid point as possible to enable micro-calibration.

The transform coefficient is calculated by using the extracted centroid point and size information of the post-rectification image. The existing method derives transform coefficients to extract a line satisfying a large number of markers at the same time. Using these transform coefficients, the centroid point of a marker that is different from the centroid point of the actually searched marker is calculated. The proposed method can obtain the pixel values for the image rectification by correctly deriving the transform coefficient from the centroid point detected with only 4 markers.

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{3}$$

The pixel (x', y') of the rectification image and the pixel (x, y) of the elemental image array are mapped using the transform coefficient calculated according to Eq. (3). In this case, if forward mapping is performed from the image to the rectified image, the coordinates calculated from the existing image are mapped to the rectified image as it is, so that there is an empty space in the rectified image without the pixel value. To solve this problem, a backward mapping method is used in which a pixel of an elemental image array mapped from a rectification image is found and a pixel value at that position is copied. In order to perform this method, we obtain the inverse-transform coefficient.

Using backward mapping, the real value is calculated instead of exact position. This real value is mapped to a more accurate pixel value through bilinear interpolation [17]. After all the pixels of the image are mapped, we can see that the distortion of the elemental image array is rectified as shown in Fig. 5.

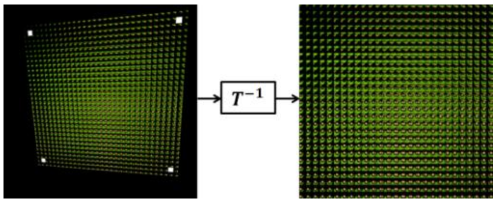

Figure 5: Experiment using backward mapping

EXPERIMENT

To improve the existing method and to investigate the effect of the proposed method, various experiments were performed. We obtained experimental images through computer and optical pickup and performed experiments on the acquired elemental image arrays.

We obtained elemental image arrays through computer pickup and optical experiments. Computer pickup images do not include distortion, so we intentionally inserted distortions. For a more accurate experiment, we calculated the position of the image as it was when picked up according to the rotation angle of x, y, z axis, and added various distortions. In the case of the optical pickup, the elemental image array was picked up after aligning as much as possible. The distortion can be corrected through the alignment of the equipment, then, the image rectification process is focused on the micro-calibration.

The existing method and the proposed method can confirm the result through the rectified image as shown in Fig. 6 and Fig. 7. We compared pixel positions calculated by the transform coefficients used in each method, and examined the influence of the center marker on the rectified image through PSNR value.

The PSNR values were calculated by comparing the two images rectified with different coefficients in Eq. (1) and (2) to the original image. Table 2 and Table 3 show that the PSNR values of the existing methods are significantly lower than those of the proposed method. In order to show the effect of the center marker, the PSNR value was calculated after filling the center marker part of the image rectified by the existing method with the elemental image.

As can be seen from each PSNR value, it was found that the transform coefficient calculated due to the problem of the middle marker and the number of markers in the existing method interferes with the correct image rectification. Thus, it can be seen that the proposed method can obtain more accurate elemental image array than the existing method.

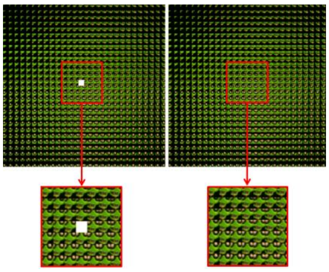

Figure 6: Computer pickup image rectified by (a) the existing method (b) the proposed method

Table 2: PSNR after rectification of computer pickup image

	Existing method	Removing center marker	Proposed method
R	26.65	29.84	**31.92**
G	25.87	28.15	**30.15**
B	27.23	32.74	**34.64**
Color	26.55	29.86	**31.86**

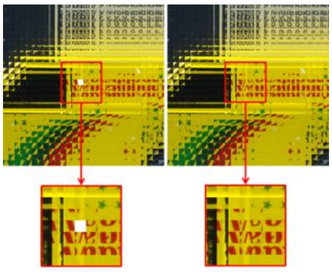

Figure 7: Optical pickup image rectified by (a) the existing method (b) the proposed method

Table 3: PSNR after rectification of optical pickup image

	Existing method	Removing center marker	Proposed method
R	32.69	33.04	**33.54**
G	31.44	32.26	**33.90**
B	28.04	34.66	**36.86**
Color	30.26	33.21	**34.53**

CONCLUSION

In this paper, we propose a preprocessing method to rectify the distortions of the elemental image array that occur during the pickup process in order to reconstruct 3D objects accurately. To effectively improve the error from the existing method, the number of markers was reduced and more accurate transform coefficient was calculated to correct the distortion. In this study, we introduce the problem of the existing method and the effect on the reconstruction image, and the results of the improvement using the proposed method are confirmed by computer and optical experiments.

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