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Analysis of Lossless Compression Methods for Elemental Image Array in Three-Dimensional Integral Imaging

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Abstract

In this paper, we analyze lossless compression methods for an elemental image array in integral imaging. The elemental image array is used for three-dimensional imaging in integral imaging. Since the quality of the reconstructed image is influenced by the resolution of each elemental image, the loss of data greatly affects the result. Thus, it is necessary to study the compression method that maximizes the image quality of the reconstructed image by reducing loss of vast elementary image array data. The existing compression methods for the elemental image array are mostly lossy compression, and no lossless compression has been studied. Analysis based on lossless compression techniques are therefore needed. In this paper, we performed several lossless compression experiments on elemental image array data and analyzed each result accordingly.

Keywords: Three-dimensional integral imaging, elemental image array, lossless compression, lens array

INTRODUCTION

Integral imaging is a technique of recording and displaying three-dimensional object using white light. It was proposed by G. Lippmann in 1908 and it is now possible to easily pick up and reconstruct 3D images through integral imaging [1]. As shown in Fig. 1, this technique consists of a pickup process for acquiring a 3D object and a reconstruction process for displaying the acquired image. In the pick-up process of integral imaging, the 3D object information is recorded in a 2D array using a lens array, and small images generated through each lens of the lens array is called an elemental image (EI). Also, a 2D array composed of elemental images is called an elemental image array(EIA). In addition to the lens array, other techniques such as camera array or camera movement can be used during the pickup process. The camera array method acquires a 3D object by fixing several cameras in an array form. This technique has an advantage in that it can acquire and reconstruct a high-resolution elemental image array, but there is a limitation that a high cost is incurred. In the camera movement method, an elemental image array is obtained by time division while moving one camera, and a high resolution image can be obtained at a low cost. However, this method has a difficulty in moving the camera without error. Therefore, because of its simple and low cost, integral imaging studies using lens arrays are conducted [2-19]. When the elemental image array acquired through the pick-up process is projected onto the same lens array again, a visual three-dimensional image is displayed due to the difference in viewpoint of each elemental image.

In order to improve the accuracy in the reconstruction process of integral imaging, the elemental image must be precisely extracted using the elemental image array rectification and extraction method [10-14]. The higher the number of elemental images and the better the quality of the elemental images, the higher the resolution of the reconstructed image. As the number of high-quality elemental images increases, the total amount of data increases, which makes it difficult to store the data in a memory or transmit in real time. Thus, an effective compression method suited to the characteristics of the elemental image array is required, and many methods have been proposed for the compression [15-19].

Image compression methods are classified into lossless compression and lossy compression. Because lossy compression has a very high compression rate, it is widely used for image compression despite image loss. However, since images in fields requiring reliability such as medical images and aerospace images do not allow any loss, they use lossless compression techniques. Most of the compression algorithms for elemental image arrays reported in the literature are lossy compression methods and there are not many studies based on lossless compression methods.

As the extracted elemental images are highly correlated with the adjacent images, they can be compressed using redundancy between elemental images, and many of the methods that have been studied compress using the features of these elemental images. The most well-known elemental image compression method is to compress the elemental image by applying it to the video compression methods [15]. First, the elemental image array is scanned in four ways: horizontal scan, vertical scan, spiral scan, and perpendicular scan to generate a one-dimensional continuous frame. Then, the generated 1D image is compressed using MPEG-2. It has proven to be very effective in the elemental image array compression. In addition, a method of applying the Karhunen-Loeve Transform(KLT) compression [16] and a method of applying 3D-DCT have been proposed using the correlation between elemental images [17]. A compression method that improves the compression rate by creating and compressing sub-image arrays with higher similarity between adjacent images than the elemental image array has also proposed [18]. Recently, a method using H.264 has been studied to maximize the efficiency of compression techniques [19]. Most of the existing methods are focused on lossy compression and almost no studies on lossless compression are found. Since data loss of elemental image has a large effect on reconstructed image quality, research on lossless compression is also needed, which has great significance.

Therefore, this paper compresses the elemental image array using lossless compression techniques of CALIC, JPEG-LS, PNG, and 3D-CALIC, respectively, and analyzes the results [20-23]. In addition, the existing method of generating and compressing one-dimensional continuous frames through scanning is applied 3D-CALIC, a lossless compression technique, and the results according to the scan order are confirmed.

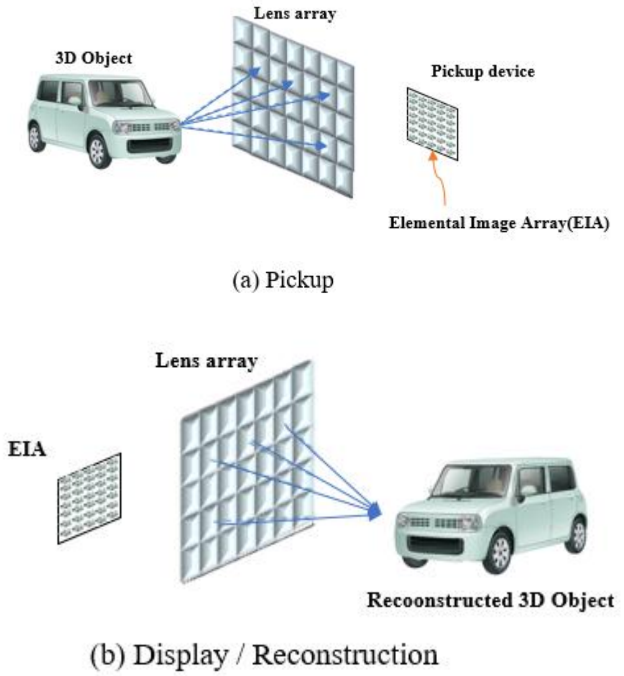

Figure. 1: Pickup and reconstruction of integral imaging

LOSSLESS COMPRESSION

1. JPEG-LS [21]

JPEG-LS is a lossless compression standard based on the LOCO-I algorithm. This compression method consists of de-correlation for predicting pixels within one frame and context coding for compressing the remaining errors. As shown in Fig. 2, it consists of a Median Edge Detector(MED), which is predictors for selecting predicted pixels according to neighboring pixels and a Golomb-rice encoder. JPEG-LS is not only low in complexity, but also has excellent performance.

	c	b	d
	a	X	

$$\hat{X} = \begin{cases} \min(a,b) \ , & c \geq \max(a,b) \\ \max(a,b) \ , & c < \min(a,b) \\ a+b-c \ , & otherwise \end{cases}$$

Figure. 2: Prediction using MED in JPEG-LS

		I_{nn}	I_{nne}
	I_{nw}	I_n	I_{ne}
I_{ww}	I_w	$\hat{I}$	

$d_h = |I_w\text{-}I_{ww}| + |I_n - I_{nw}| + |I_n\text{-}I_{ne}|$

$d_v = |I_w\text{-}I_{nw}| + |I_n - I_{nn}| + |I_{ne}\text{-}I_{nne}|$

$D = d_v - d_h$

$IF\ (D > 80)\quad \hat{I} = I_w$

$ELSE\ IF\ (D < -80)\quad \hat{I} = I_n$

$t = (I_n + I_w)/2 + (I_{ne} - I_{nw})/4$

$ELSE\ IF\ (D > 32)\quad \hat{I} = (t + I_w)/2$

$ELSE\ IF\ (D > 8)\quad \hat{I} = (t + I_n)/2$

$ELSE\ IF\ (D < -32)\quad \hat{I} = (3t + I_w)/4$

$ELSE\ IF\ (D < -8)\quad \hat{I} = (3t + I_n)/4$

$ELSE\quad \hat{I} = t$

Figure. 3: Prediction using GAP in CALIC

2. CALIC [20]

CALIC (Context-based, adaptive, lossless image codec) is composed of de-correlation and context coding like JPEG-LS. As shown in Fig. 3, Gradient-Adjusted Prediction (GAP) is used to select a prediction pixel according to the directionality and edge strength of neighboring pixels. Unlike other compression techniques, it is predicted by using more pixels non-linearly. CALIC uses an adaptive arithmetic coder based on context modeling. This method has a higher compression rate than other lossless compression techniques, but has a high complexity due to a large amount of computation.

3. 3D-CALIC [22]

CALIC is a technique for compressing two-dimensional images using an intra-frame compression, and 3D-CAIC is an inter-frame compression for extending it to a three-dimensional multiband image [22, 23]. Most images including color images (RGB, LAB, CMYK, etc.) and aerial satellite images, are multispectral. In addition, since there is a correlation between each frame, a compression method suitable for this has been studied. 3D-CALIC, which is a representative compression thereof, predicts each frame using a previous frame which is a reference band, and predicts from pixels at the same position in the previous frame and neighboring pixels, as shown in Fig. 4.

	x_7	x_6	
x_8	x_3	x_2	x_4
x_5	x_1	x	

X : Reference band

	y_7	y_6	
y_8	y_3	y_2	y_4
y_5	y_1	y	

Y: Prediction in 3D-CALIC

$$\widehat{y_h} = y_1 + \alpha(x - x_1)$$
$$\widehat{y_v} = y_2 + \alpha(x - x_2)$$

$$IF(|x - x_2| - |x - x_1|\} > T)\quad \hat{y} = \widehat{y_h}$$
$$ELSE\ IF(|x - x_2| - |x - x_1|\} < -T)\quad \hat{y} = \widehat{y_v}$$
$$ELSE\quad \hat{y} = (\widehat{y_v} + \widehat{y_h})/2$$

$T : threshold(T = 90)$

Figure. 4: Prediction using Reference band in 3D-CALIC

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EXPERIMENTS

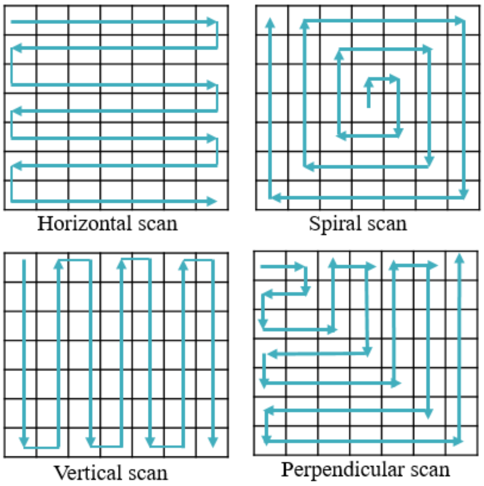


Figure. 5: Scan mode for 3D-CALIC

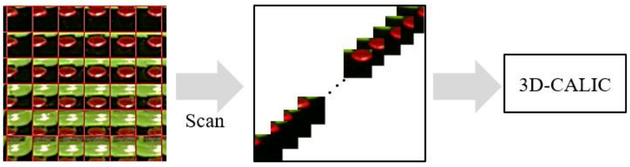


Figure. 6: Flowchart of the proposed method

In this paper, we experiment to confirm the results of lossless compression for elemental image arrays in three-dimensional integral imaging which have not been studied previously. First, the elemental image array is extracted the elemental image extraction method. Table 1 shows the size of each elemental image, the size of the 2D elemental image array, and the number of elemental images for the three test images picked up. The obtained elemental image arrays are compressed using the lossless compressions CALIC, JPEG-LS, PNG, and 3D CALIC, respectively.

Among existing compression methods for elemental images, the compression method using video compression techniques have been studied [15]. In this method, each elemental image is scanned to form a one-dimensional frame, which is regarded as a video frame and applied. The elemental images before compression are rearranged into a 1D image by scanning. Four proposed methods are horizontal scan, vertical scan, spiral scan, and perpendicular scan. Figure 5 shows each scan method. In this paper, we apply the elemental image scanning method to 3D-CALIC, a lossless compression technique. The overall flow chart for this is shown in Fig. 6.

$$\text{Compression rate} = \frac{\textit{Original image size}}{\textit{Compressed image size}} \qquad (1)$$

Table. 1: Specifications of EIAs used in the experiments

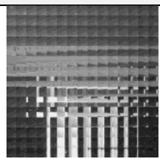
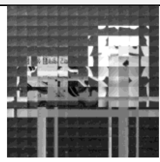
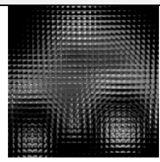
File name	Test1	Test2	Test3
			
EI size	214	215	26
Width	3,210	3,240	806
Height	3,210	3,240	806
#EI	15x15=225	15x15=225	31x31=96

Table. 2: Results of compression experiments

Scan method	Test1	Test2	Test3
Horizontal	2.085	2.142	1.852
Vertical	2.089	2.136	1.755
Spiral	2.079	2.139	1.821
Perpendicular	2.077	2.144	1.8

Table. 3: Results of compression experiments

Compression	Test1	Test2	Test3
CALIC	2.419	2.495	2.309
JPEG-LS	2.383	2.463	2.284
PNG	1.996	2.063	1.825

Table 2 and Table 3 show the result of compression test of elemental image arrays according to each lossless compression technique. The results shown in the table are the compression ratio according to equation (1), which is expressed as the original image size divided by the compressed image size. As can be seen in Table 2, the results of the four scan sequences for the elemental image array were not different from those in the case of applying the video compression. Thus, it can be seen that the scanning order does not greatly affect the 3D-CALIC compression. The results of the three lossless compression schemes in the frame is shown in Table 3. We confirmed that CALIC is the best compression method as we know it, but we can see that it does not have a big difference from other compression methods.

CONCLUSION

In this paper, we analyzed the elemental image array compression according to the lossless compression technique in three-dimensional integral imaging. Since many studies on compression of elemental images proposed are focused on lossy compression, studies based on lossless compression are necessary and significant. We confirmed the results of CALIC, JPEG-LS, and PNG, which are intra-frame compression and 3D-CALIC, which is an inter-frame compression, in the elemental image array acquire through pickup device. We also conducted 3D-CALIC experiments with several scanning methods. The results of the analysis of the elemental image array compression method and the lossless compression method which have been studied will be a great basis for a research on a method of compressing elemental images more effectively.

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