Three-Dimensional Auto-Stereoscopic Image Recording, Mapping and Synthesis System for Multiview 3D Display

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In this paper, we present a 3D auto-stereoscopic image recording, mapping and synthesis system for multiview 3D display. Recursive storage and mapping techniques are addressed to reduce hardware costs for lenticular-based multiview 3D display. Multiview images are synthesized according the recursive storage and mapping rules to present a distinct 3D image. The experimental results prove the proposed scheme has low hardware costs and a realistic 3D feeling.

***Index Terms*—Auto-stereoscopic, 3D image recording, 3D mapping, 3D synthesis, multiview 3D display.**

I. INTRODUCTION

THE DEVELOPMENT of stereoscopic display technology has led to 3D related research. Auto-stereoscopic display technology provides convenience and comfortable vision and plays an important role in 3D displays.

Lenticular-based 3D display is an important form of glassless 3D display [1]–[7]. Lenticular lenses refract multiview images to the observer and create a 3D vision effect. Armour proposed a printer optimization for lenticular screening [2]. Braspenning discussed visual quality assessment of lenticular-based 3D displays [3]. Kim presented non-integer view multiplexing for 3D lenticular display [4]. Boer developed switchable lenticular-based 2D/3D displays [5]. Woodgate improved the traditional structure to achieve a 3D lens array structure [6]. Huang designed an auto-stereoscopic 3D display using a tunable liquid crystal lens array that mimics the effects of the GRIN lenticular lens array [7]. Mapping accuracy determines 3D vision quality. Determining how to perform accurate 3D image mapping from multiview image sources is key to developing techniques. In addition, multiview image sources require a great amount of storage space. Reducing the memory space and cost is another important issue. In order to solve the above problems, we propose a recursive-based 3D auto-stereoscopic image recording, mapping, and synthesis system for multiview 3D display.

This paper develops a 3D synthesis and mapping technology based on lenticular auto-stereoscopic display. The system captures nine-view images (two-dimensional images) according to a multiview angle. Then multirate signal processing is performed to scale the size of the images. Afterward, we establish a recursive-mapping rule based on sub-pixel arrangement and regulation of the 3D display. The proposed scheme considers the precision and accuracy of sub-pixel mapping and provides realistic images. In order to achieve the presented algorithm, we adopt the Xilinx FPGA development platform to implement the 3D image storage, recording, synthesis, and mapping system [8].

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In this paper, we propose a 3D image mapping architecture that adopts nine-view image data according to the multiview image arrangement rule without depth map information. The proposed scheme uses a recursive-mapping technique and reduces the hardware overhead to provide a better solution for auto-stereoscopic display. The experimental results show that this approach creates realistic 3D vision and provides an efficient solution to 3D recording and synthesis research.

II. 3D AUTO-STEREOSCOPIC IMAGE RECORDING, MAPPING AND SYNTHESIS SYSTEM

Three-dimensional auto-stereoscopic multiview images have symmetrical, regular, and recursive characteristics. If we employ the features well, we will design a 3D synthesis circuit with low hardware costs. First, we employ nine cameras to capture multiview (nine-view) images (Fig. 1). Then the multiview images are analyzed according to their view numbers and an index of RGB sub-pixels (Fig. 1). Afterward, multirate processing is performed to scale the image size based on the size of the multiview image [9], [10]. We adopt an interpolator and interpolation filter to scale up the image size (Fig. 2(a)). The interpolation filter adopts a low-pass filter to solve the aliasing effect after up-sampling. Oppositely, we use a decimator and a decimation filter to scale down the image size (Fig. 2(b)). The decimation filter process runs before down-sampling to provide accurate data. In order to provide high-quality images, we adopt bi-cubic interpolation, which provides better approximation of real points, to interpolate the missing data [11] as follows:

$$f_{(i+u,j+v)} = \begin{bmatrix} u_{(u+1)} & u_{(u+0)} & u_{(u-1)} & u_{(u-2)} \end{bmatrix} \cdot \begin{bmatrix} f_{(i-1,j-1)} & f_{(i-1,j+0)} & f_{(i-1,j+1)} & f_{(i-1,j+2)} \\ f_{(i+0,j-1)} & f_{(i+0,j+0)} & f_{(i+0,j+1)} & f_{(i+0,j+2)} \\ f_{(i+1,j-1)} & f_{(i+1,j+0)} & f_{(i+1,j+1)} & f_{(i+1,j+2)} \\ f_{(i+2,j-1)} & f_{(i+2,j+0)} & f_{(i+2,j+1)} & f_{(i+2,j+2)} \end{bmatrix} \begin{bmatrix} u_{(v+1)} \\ u_{(v+0)} \\ u_{(v-1)} \\ u_{(v-2)} \end{bmatrix}$$

After the scaling process, we perform synthesis and mapping on the multiview 3D images. First, we consider the specifications of the 3D display. Then we calculate the position and distance of each view and each pixel. Next, we arrange the multiview 3D stream according to the spatial distribution of the 3D

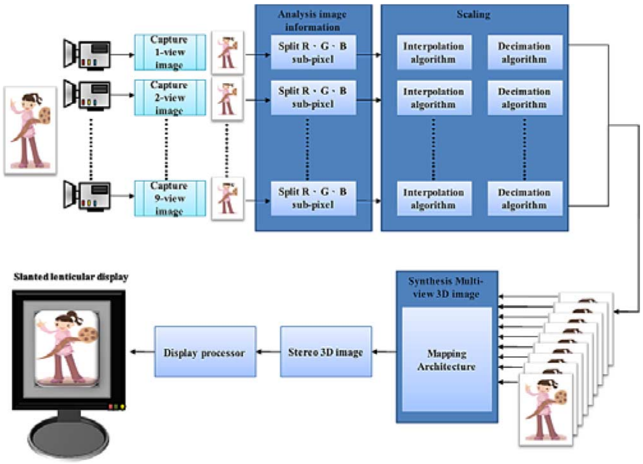

Fig. 1. System block diagram of 3D Auto-stereoscopic image recording, mapping and synthesis system for multiview 3D display.

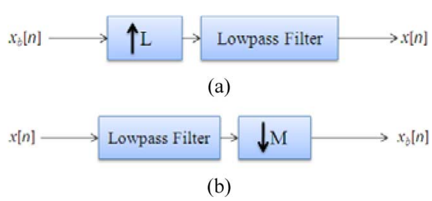

Fig. 2. Multirate system (a) Up-sampling system. (b) Down-sampling system.

display. We achieve a recursive recording and mapping scheme for multiview 3D synthesis as follows (Fig. 3). We define the view number as n. Variable R stands for red sub-pixels. The synR(x, y) is the synthesized image coordinate. The view_n(x, y) describes the multiview image coordinate. The recursive mapping and storage strategy reduces the hardware cost and provides accurate multiview data mapping (Fig. 4). In addition, the multirate pre-processing reduces the quantity of data, thereby reducing the memory requirement.

$$\text{if (view} = \text{n)}$$
$$\{$$
$$\text{if (y mod } 9 = \text{R}_1 \text{ \&\& x mod3} = 1)$$
$$\text{synR(x, y)} = \text{view\_n(x, y);}$$
$$\text{elseif (y mod } 9 = \text{R}_2 \text{ \&\& x mod } 3 = 2)$$
$$\text{synR(x, y)} = \text{view\_n(x, y);}$$
$$\text{else (y mod } 9 = \text{R}_3 \text{ \&\& x mod } 3 = 0)$$
$$\text{synR(x, y)} = \text{view\_n(x, y);}$$
$$\}$$

We adopt XILINX Spartan-3A DSP 3400A development board to perform the system. The Spartan-3A utilizes a MicroBlaze processor to control the system in Fig. 5. In addition, we adopt a read buffer memory that includes DDR SDRAM as the frame buffer. TFT IP provides a timing controller for

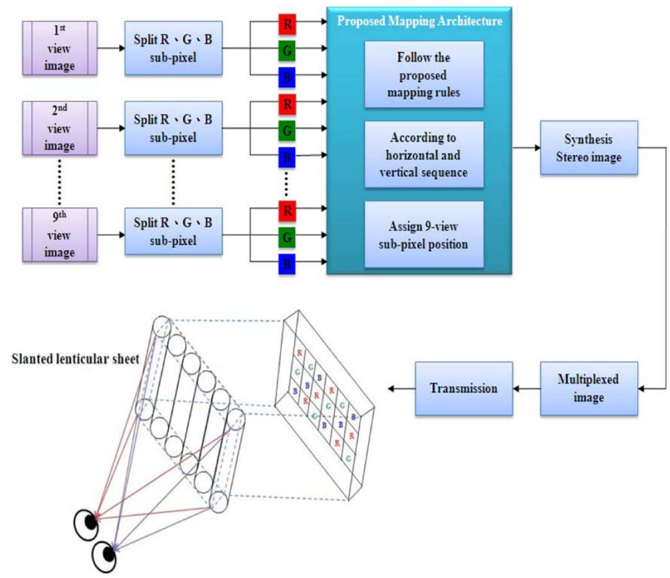

Fig. 3. Recursive-based 3D auto-stereoscopic image mapping flow for multiview 3D display.

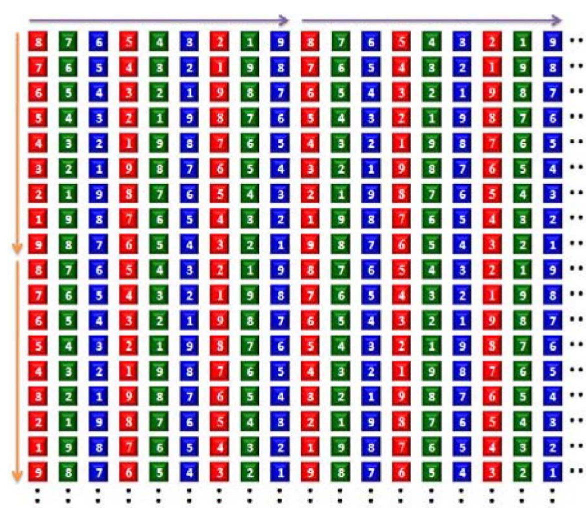

Fig. 4. Multiview image synthesis and mapping picture.

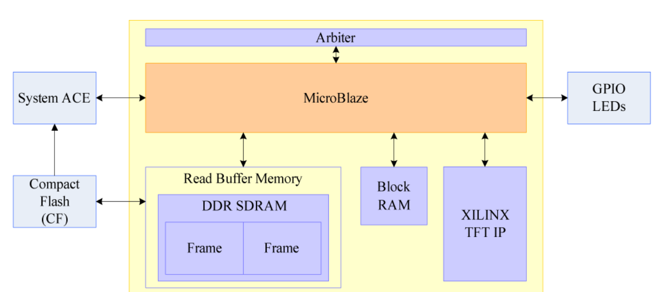

Fig. 5. System architecture using XILINX Spartan-3A DSP 3400A development board.

the 3D display. We store the program in compact flash. The MicroBlaze processor accesses the program memory through system ACE in Fig. 5.

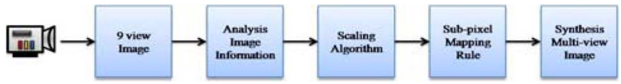

Fig. 6. Simulation flow of 3D Auto-stereoscopic image recording, mapping and synthesis system.

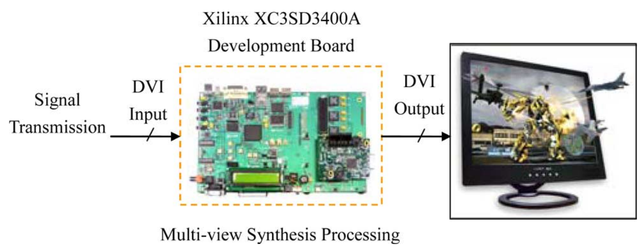

Fig. 7. Hardware platform of 3D Auto-stereoscopic image recording, mapping and synthesis system.

TABLE I
HARDWARE RESOURCE USAGE OF XILINX XC3SD3400A DEVELOPMENT BOARD

Hardware Resource Usage of XILINX XC3SD3400A Development Board			
Logic Utilization	Usage	Total	Usage Rate
Slices	10509	23872	44%
Total Memory Usage (Block RAM)	1890Kb	2268Kb	83%

III. EXPERIMENTAL RESULTS

In this section, we introduce the experimental results of the proposed system. We describe the simulation flow in Fig. 6. First of all, we adopt nine cameras to capture multiview images. Then the image information is analyzed. Next, we adopt a multirate algorithm to scale the images, including up-sampling and down-sampling processing. Afterward, sub-pixel mapping rules are performed according to different methods. After image synthesis, a 3D image appears on the 3D display. Subjective judgment is used to determine the 3D image quality depending on the 3D display results.

Fig. 7 describes the hardware platform of the 3D auto-stereoscopic image recording, mapping and synthesis system. A DVI signal is transmitted into the Xilinx XC3SD3400A development board. After recording, mapping, and synthesis in the development board, we utilize DVI output to send the multiview 3D signal to the 3D display.

Table I analyzes the hardware resource usage of the XILINX XC3SD3400A development board. Our system uses 10509 slices and 1890Kb blocks of RAM. The slice usage rate is 44%, and memory usage rate is 83%.

Fig. 8 compares the flow of multiview scaling for the 3D display. The first group of images adopts the original image and utilizes our synthesis scheme to display a 3D image. The second group of images uses a multirate algorithm to down-sample the images. Then we adopt different interpolation methods to scale the images. Next, the proposed scheme synthesizes the 3D images. Table II presents the experimental results of different interpolation methods and scale factors. The proposed bi-cubic based 3D synthesis, mapping and recording system has better quality. In addition, the interpolation filter and decimation filter reduce aliasing effects to provide higher 3D image performance in this system.

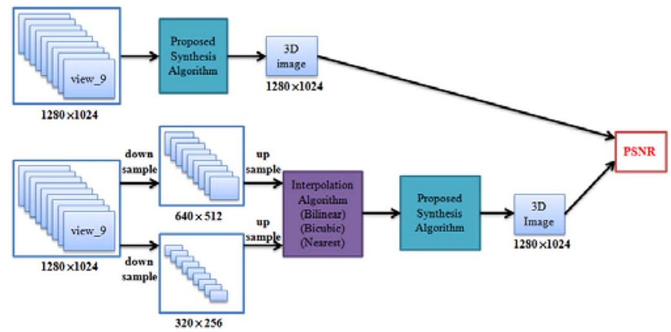

Fig. 8. Comparing flow of multiview scaling for 3D display.

TABLE II
HARDWARE RESOURCE USAGE OF XILINX XC3SD3400A DEVELOPMENT BOARD

Hardware Resource Usage of XILINX XC3SD3400A Development Board			
Method	Nearest Algorithm	Bilinear Algorithm	Bicubic Algorithm
Scale Factor = 2	32.7045	34.7305	36.4081
Scale Factor = 4	26.7871	27.1723	27.6711

TABLE III
COMPARISON OF 3D AUTO-STEREOSCOPIC IMAGE RECORDING, MAPPING AND SYNTHESIS SYSTEM

Method	Advantages	Disadvantage
Lim [12]	Simultaneous intermediate view interpolation and multiplexing algorithm reduce image artifacts.	The system requires extra depth information to provide multi-view images.
Jiang [13]	This method adopts a spatial multiplex arrangement to provide multi-view images without depth information to generate 3D images.	This architecture only processes 128 × 128 3D images. It is used only for small 3D displays.
Lo [14]	This method proposes an image scaling concept to overcome the problems of different 3D image sizes and sources. In addition, this scheme can display 3D images on different 3D displays.	This method captures multi-view images using a man-made mode. This scheme has contrived errors.
Proposed Method	The proposed method produces 3D images without depth information and adopts a multi-rate algorithm to provide higher image performance on different 3D displays.	The proposed 3D synthesis system has higher computing complexity and processing time.

Table III compares the 3D auto-stereoscopic image recording, mapping, and synthesis system. Lim [12] proposed a simultaneous intermediate view interpolation and multiplexing algorithm to reduce 3D image artifacts. The system needs extra depth information to provide multiview images. Jiang [13] adopted a spatial multiplex arrangement to provide multiview images without depth information to generate 3D images. This architecture only processes 128×128 3D images. It is used only for a small 3D display. Lo [14] presented an image scaling

Fig. 9. Proposed multiview image display using XILINX XC3SD3400A Development Board (Content source [15]: i-Art Corporation, http://www.i-art.com.tw).

concept to overcome the problems of different 3D image sizes and sources. In addition, this scheme can display 3D images on different 3D displays. This method captures multiview images using a man-made mode. However, this scheme has contrived errors. We propose a 3D auto-stereoscopic image recording, mapping, and synthesis system for a multiview 3D display. The proposed method develops 3D images without depth information and adopts a multirate algorithm to provide higher image performance on different 3D displays. The drawback of the proposed 3D synthesis system is the higher computing complexity and processing time. Fig. 9 shows the proposed multiview image display using the XILINX XC3SD3400A development board.

IV. Conclusion

In this paper, we present a 3D auto-stereoscopic image recording, mapping, and synthesis system for a multiview 3D display. Multi-rate processing, recursive 3D data storage, and mapping techniques are achieved in this system. The proposed method reduces memory space and hardware requirements. At the same time, the scheme performs accurate 3D information mapping and synthesis and provides realistic 3D images.

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References

[1] A. Schmidt and A. Grasnick, "Multi-viewpoint auto-stereoscopic displays from 4d-vision," in *Proc. SPIE Stereoscopic Displays Virtual Reality Syst. IX*, Jan. 2002, vol. 4660, pp. 212–221.

[2] J. D. Armour and D. L. Lau, "Printer optimization for lenticular screening," in *Proc IEEE Southeastcon*, Apr. 2008, pp. 226–230.

[3] R. Braspenning, E. Brouwer, and G. de Haan, "Visual quality assessment of lenticular based 3D displays," in *Proc. Eur. Signal Process. Conf.*, Sept. 2005.

[4] C. Kim and J. B. Ra, "Non-integer view multiplexing for 3D lenticular display," in *Proc. IEEE 3DTV Conf.*, May 2007, pp. 1–4.

[5] D. K. G. de Boer, M. G. H. Hiddink, M. Sluijter, O. H. Willemsen, and S. T. de Zwart, "Switchable lenticular based 2D/3D displays," in *Proc. SPIE Photonics Multimedia*, Apr. 2006, vol. 6196.

[6] G. J. Woodgate and J. Harrold, "Lens array structure," U.S. Patent US2006/0152812 A1, Jul. 2006.

[7] Y. Kao, Y. Huang, K. Yang, P. C.-P. Chao, C. Tsai, and C. Mo, "An auto-stereoscopic 3D display using tunable liquid crystal lens array that mimics effects of GRIN lenticular lens array," in *Proc SID'09 Dig.*, 2009, pp. 111–114.

[8] Y. C. Fan, Y. T. Kung, and B. L. Lin, "3D auto-stereoscopic image recording, mapping and synthesis system for multi-view 3D display," in *2010 Int. Asia-Pacific Data Storage Conf.*, Hualien, Taiwan, Oct. 27–29, 2010, APDSC 2010.

[9] R. E. Crochiere and L. R. Rabiner, "Interpolation and decimation of digital signals—a tutorial review," *Proc. IEEE*, vol. 69, no. 3, pp. 300–331, Mar. 1981.

[10] M. Vetterli, "A theory of multi-rate filter banks," *IEEE Trans. Aoustics, Speech Signal Process.*, vol. AASSP-35, pp. 356–372, Mar. 1987.

[11] X. G. Zhang, "A new kind of super-resolution reconstruction algorithm based on the ICM and the bi-cubic interpolation," in *Proc. IEEE Int. Symp. Intelligent Inf. Technol. Application Workshops (IITAW 2008)*, Dec. 2008, pp. 817–820.

[12] H. S. Lim, S. H. Kim, Y. G. Lee, L. S. Kim, J. B. Ra, and H. W. Park, "Simultaneous intermediate-view interpolation and multiplexing algorithm for a fast lenticular display," in *Proc. SPIE Opt. Components, Detectors, Display*, Nov. 2007, vol. 46.

[13] J. C. Jiang, "LTPS-TFT digital cell library apply 2d-to-3d conversion system for three-dimensional video," Master's thesis, National Taipei University of Technology, Taiwan, 2008.

[14] T.-C. Lo, "Stereo image based on 2d-to-3d processor of three-dimensional display system," Master's thesis, National Taipei University of Technology, Taiwan, 2009.

[15] [Online]. Available: http://www.i-art.com.tw Content source: i-Art Corporation.