Scalable high-resolution integral videography autostereoscopic display with a seamless multiprojection system

Hongen Liao, Makoto Iwahara, Takefumi Koike, Nobuhiko Hata, Ichiro Sakuma, and Takeyoshi Dohi

We propose a scalable high-resolution autostereoscopic display that uses integral videography (IV) and a seamless multiprojection system. IV is an animated extension of integral photography (IP). Although IP and IV are ideal ways to display three-dimensional images, their spatial viewing resolution needs improvement; the pixel pitch of the display and the lens pitch are the main factors affecting IV image quality. We improved the quality by increasing the number and density of the pixels. Using multiple projectors, we create a scalable high-resolution image and project it onto a small screen using long-focal-length projection optics. To generate seamless IV images, we developed an image calibration method for geometric correction and color modulation. We also fabricated a lens array especially for the display device. Experiments were conducted with nine XGA projectors and nine PCs for parallel image rendering and displaying. A total of 2868 × 2150 pixels were displayed on a 241 mm × 181 mm (302.4 dots/in.) rear-projection screen. The lens pitch was 1.016 mm, corresponding to 12 pixels of the projected image. Measurement of the geometric accuracy of the reproduced IV images demonstrated that the spatial resolution of the display system matched that of the theoretical analysis. © 2005 Optical Society of America

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1. Introduction

Integral photography (IP)1 is an ideal way to display three-dimensional (3-D) autostereoscopic images. Spatially formatted visible images can be formed from an arbitrary viewpoint without use of any supplementary glasses or tracking devices. This autostereoscopic technique is also called fly’s eye lens photography because of its use of an array of tiny lenses and a film for capturing and displaying images. A number of elemental images are recorded on the film. When the film is placed at the same position relative to the lens array and is irradiated with a diffused light, the rays retrace the original routes and reproduce the image at the same position as the located object. With IP, both horizontally and vertically varying directional information is used and thus a full parallax image is produced, making it a promising method for creating 3-D autostereoscopic displays.

We previously developed integral videography (IV),2 which is an animated extension of IP. With IV, a fast image rendering algorithm is used to project a computer-generated graphical object through a microconvex lens array. Each point shown in a 3-D space is reconstructed at the same position as the actual object by the convergence of rays from the pixels of the elemental images on the computer display after they pass through the lenslets in the lens array. Switching to scene mode enables IV to display animated objects.

IP and IV have attracted much attention for still photography and video in a variety of 3-D image fields. Okano et al. developed a real-time pickup and 3-D display system based on IP,3 and Arai et al. used a gradient-index lens array and a high-definition TV camera for IP image pickup to solve the pseudoscopic problem.4 Igarishi et al. proposed a method that generates elemental images by the computer process instead of the real object pickup process, called
computer-generated integral photography, can be implemented in either real IP mode or virtual IP mode. Recent studies focused on widening the viewing angle of the IP image and on enhancing the depth of IP images. Jung et al.’s wide-viewing-angle integral imaging uses orthogonal polarization switching and an aspheric Fresnel lens array. Park proposed a method for enhancing the depth of IP by using the birefringence of a uniaxial crystal plate.

Although the advantages of IP and IV have been demonstrated in both feasibility studies and medical applications, an unresolved issue is the image quality (viewing resolution) of the reconstructed 3-D image. The resolution limitation of IP was studied by Burckhardt and Okoshi. In Hoshino et al.’s resolution theory, the image that an observer actually views depends on the position of the viewer and the image. Kishk and Javidi presented a high-resolution technique for passively sensing and recognizing 3-D objects that uses computational IP. A synchronously moving micro-optics imaging system is used for image pickup and display to improve the viewing resolution. Erdmann and Gabriel used a 3-D camera system with a scanning microlens array to pick up the image and a relay lens to match the element image pitch on the CRT to that of the microlens array. Although these methods enable high-resolution 3-D imaging for IP, they are not sufficient for real-time 3-D imaging.

In addition to aberration and lens deviation, there are two important factors affecting the viewing resolution of IV. One is the lens pitch, which determines the spatial resolution ratio in image reconstruction. The lens pitch cannot be made too small because the diffraction effect would degrade the viewing resolution. The other factor is the resolution and pixel density of the two-dimensional (2-D) element image, which are the components of the 3-D image to be reconstructed. To the best of our knowledge, the current available full-color display devices have a maximum pixel density of approximately 200 dots/in., making it difficult to realize high-resolution 3-D imaging.

In our previous study, the IV images were limited in quality due to the theoretical binding of the IV image resolution to the pixel density of the display (as in LCD). We proposed a fundamental principle of multiprojection for increasing both image resolution and pixel density and developed a two-projector-based display system for a high-resolution IV display. Misalignment and image distortion of multiple projection images are challenging issues in the development of a scalable high-resolution IV display by use of more projectors.

We have now developed a multiple-projector display using a long-focal-length projection technique to achieve scalable high-quality IV images. We also developed an image calibration method for geometric correction and color modulation of a generated seamless IV image. In Section 2 we describe a spatial resolution analysis of IV images, our contribution to developing a high-resolution IV display by use of a scalable multiprojection technique, an image calibration method for geometric correction and color modulation, and a lens array for image formation. In Section 3 we describe our experimental evaluation of the developed IV display device, and in Section 4 we discuss the results and possible means of improving the quality of image. We conclude in Section 5 with a brief summary.

2. System

A. Spatial Resolution of Integral Videography Images

In viewing IP and IV images, the spatial frequency of the actual image is limited by the pixel pitch of the element image and the characteristics of the microlens. Assuming the maximum projected frequency through the lens to be $\alpha_{i,\text{max}}$ cycles per radian (cpr) (Fig. 1), the corresponding maximum viewing spatial frequency is

$$\beta_{i,\text{max}} = \frac{z_i}{|L - z_i|},$$

where $z_i$ is the viewer–image distance and $L$ is the viewing distance.

The theoretical limit of the spatial resolution of IP and IV images is governed by the sampling effect and depends on the distance of the viewer from the microlens array. The spatial Nyquist frequency in cycles per radian (cpr) is given by

$$\beta_{\text{Nyq}} = \frac{L}{2p}.$$

Suppose the focal length $f$ of the lens is equal to a gap $g$ between the lens and the element image and the element image is projected as parallel rays. When the lens pitch is small, the resolution on focusing error at any depth position $z_i$ is higher than either the 2-D resolution, $\beta_{\text{Nyq}}$, or the resolution determined by the diffraction limit. In this case the focusing error has no effect on the overall resolution. However, the lens pitch is not negligible in practice; the resolution of an image produced near the observer is lower and is determined by the focusing error. The resolution degradation due to the focusing error can be improved by proper adjustment of the focal length of the lens.
The angle resolution due to the sampling effect and the element image resolution, depending on viewer–image distance $z_i$, is given by \(^{14}\)

$$\beta_{\text{max}} = \beta_{\text{Nyq}} \min\left( D \frac{z_i}{|L - z_i|}, 1 \right). \tag{3}$$

The depth factor is defined as the ratio of the maximum projected frequency to the Nyquist frequency:

$$D = \frac{\alpha_{i \text{max}}}{\beta_{\text{Nyq}}} \tag{4}$$

In Eq. (3), $\beta_{\text{Nyq}}$ indicates the 2-D resolution as a flat image produced on the plane of the lens, where the term min (.) indicates the resolution degradation that depends on the image position. When depth factor $D$ is large, the resolution degradation of an image produced far from the lens is better.

B. Scalable, High-Resolution, High-Density Multiprojection Images

The most economical approach for displaying high-resolution, large-format images is to use an array of projectors emitting rays to a front or rear panel screen.\(^ {20}\) Several frameworks have been designed to facilitate the applications for display walls and similar display devices. Some of these works focus on virtual reality applications\(^ {21}\) and immersive display,\(^ {22}\) while others focus on the high-resolution display like large tiled display\(^ {23}\) and multiple-projector systems.\(^ {24}\) Bresnahan et al. developed a large-scale, high-resolution rear-projection technique for a passive stereo display system. Multiple workstations drive a corresponding number of projectors to produce high-resolution stereo images.\(^ {25}\)

Our display system has a $3 \times 3$ array of projectors (Fig. 2) and produces high-resolution images on a rear-projection screen. The projected images are reflected by a series of two to four mirrors before reaching the screen—those from the left and the right are reflected four times, and those from the middle are reflected twice by mirrors. The focus of each projector is adjusted based on its distance from the screen. The projectors are firmly attached to a metal frame to prevent the vibration of the color filters and fans from affecting the displayed image. We manually align the projectors by using projector mounts with 6 degrees of freedom. This alignment is laborious and yet does not yield precise alignments (one or two pixels average discontinuity).

Although a normal multiprojection technique can produce high-resolution images, the pixel density of the projected images is too low to create an autostereoscopic image. High pixel density is needed for the image projection used in an IV autostereoscopic display. We use long-focal-length projection to produce small, high-pixel-density (small-pixel-pitch) images. By adjusting the combination and arrangement of the lenses, we achieved a new long-focal-length projection optics. The density of pixels in the projected images exceed 300 pixels/in. (ppi); an image can be less than 87 mm $\times$ 65 mm.

We wanted to maximize the number of pixels displayed, but image blending would sacrifice a large percent of pixels, especially around the four edges of each center row image. The key to making our display accurate is to edge match each projected image to its neighbor without overlay or separation lines.

C. Image Calibration and Correction

Tiling multiple projectors is a viable way to build a high-resolution display system. However, aligning the projectors becomes a challenging issue when more than a few projectors are used. Projector geometric calibration was the first stumbling block we encountered. Vibration, heat expansion, and lamp changes can cause several pixels of drift per week, even with firmly attached projectors. Color balancing all projectors also proved a difficult task. Although the color output of each projector varies slightly, the color output of the xenon lamps varies greatly between bulbs and changes over time. A well-color-balanced display will drift out of balance after only a few weeks of use.

An important issue is thus the coordination of multiple projectors to achieve seamless edge blending and precise alignment. Seamless edge blending means removal of the visible discontinuities between the images of adjacent projectors. Aligning the projectors by hand is a time-consuming task that requires both skill and experience.

We developed a computer-assisted geometric correcting and color-balancing system in which the image position and color adjustment parameters are fed into a computer or special image processing graphics board and used to adjust each projector’s image position and color through a serial input (Fig. 3). We use edge-blending techniques to overlap the edges of the projected, tiled images and to blend the overlapped pixels to smooth the luminance and chromaticity transition from one image to the next. With these
techniques, only coarse physical alignment of the projectors is required.

A digital camera is used to obtain precise alignment (or misalignment) information for the projected multiple images. We zoom the camera to focus on a relatively small region of the display screen and move the camera across the screen to get a broader coverage. The camera measures point correspondences and line matches between neighboring projected images through the microconvex lens array directly.

The measurement includes two phases, geometric measurement and color measurement. The geometric measurement is performed first. We use a gray code pattern to obtain the correspondence between the lens position and the projected image. The pattern is projected from each projector and is used to determine that the arbitrary pixels on a projector (projected coordinate) are equivalent to each pixel on a camera (camera coordinate). Since twice the resolution is obtained when the gray code is increased by one measurement number, the correspondence between the projected coordinates and the camera coordinates can be found with a sufficient number of measurements. Figures 4(a) and 4(b) show the gray code patterns used for horizontal and vertical measurements of the relationships between the positions of the projected images and the lenses.

The combination of camera coordinates for arbitrary measurement positions and projected coordinates is calculated with this calibration data. For the color measurement, the projected images are calibrated from a fixed point, the color is adjusted between adjoining fields, and a color compensation parameter is generated. These two sets of compensation data are unified, and we transfer the calibration information to the digital signal processor image processing board for use in adjusting the source image before it is displayed by the misaligned projectors. Next we show how to presume the central pixel position of each lens from a measuring point.

We adjust the projection system within the scope of the error permitted by the optical system and measure the actual and designed position relationships between the microlens and the projected pixels (Fig. 5). We perform the measurement using the calculated image deformations. We assume that pixel $x_c(i, j)$ is located directly under a microlens $(i, j)$. In fact, because of the setting method and optical system error, pixel $x_c(i, j)$ is not definitely located directly under microlens $(i, j)$, but rather is projected on a different position, $x_p(i, j)$, as shown in Fig. 5.

$$x_p + n(\delta_p + \xi_p) = a(x_c + n\delta_c), \quad (n = \pm 1, 2, 3, \ldots), \quad (5)$$

where the projector coordinate is $x_p$, the camera coordinate is $x_c$, $\delta$ is the distance from the center lens, and $\xi$ is the difference in distance of the lens center. $a$ is a proportionality coefficient between the camera coordinates and the projected coordinates. $n(n$
is an integer value and represents the \( n \) adjacent lenses. The left side of Eq. (5) expresses the projected coordinates, and the right side expresses the camera coordinates. Therefore Eq. (5) turns into simultaneous equations.

We analyzed the position information and calculated the deformation of the projected image using the measurement data in three steps (presumed procedure). (1) Near the central position of camera photography, as \( \xi \ll \delta \), the solution is calculated with the simultaneous equations. (2) Since there is a measurement error and some points cannot be found, the other points are estimated by interpolation and extrapolation. (3) Geometric deformation is performed on the basis of the measurement data since the number of pixels that should be under each microlens is known.

D. Digital Signal Processor Board for Image Processing

The video image output from each PC was not directly supplied to the projectors; rather the video signal was passed through image processing hardware that worked as a filter to geometrically warp and modulate the color of the image encoded in the video signal. We developed image processing hardware for geometry correction and color balancing. This hardware enables real-time processing of any type of geometric warping and the color modulation of individual pixels.

The geometric warping was done as an inverse mapping with bilinear interpolation. The parameters for the geometric warping were stored as a table of the coordinates of the source pixels for every pixel of the output image data. We set the coordinate of a source pixel with a subpixel resolution of 4 bits. To support arbitrary mapping, we needed random access to the input frame. Hence the input image was alternately buffered to a dual-port frame memory. While one frame memory was being filled, pixel data were read from another frame memory based on the table of coordinates for the inverse mapping.

Color modulation for individual pixels was necessary not only for edge blending but also to correct the color uniformity of the projected image. The color modulation function was specified with a segmented linear function with nine vertices. The color modulation was applied to the color data of the pixels that were generated in the previous inverse mapping module.

A block diagram of the image processing hardware is shown in Fig. 6. The color data of a pixel has 24 bits at the output of the video signal input interface block. After the 24-bit color data are converted to 30-bit color data with the LUT0 look-up table, the 30-bit computation accuracy can be maintained in the data processing of the geometric warping and the color modulation. A look-up table is used so that the color data are proportional to the physical intensity of the light. This processing is necessary to obtain the correct antialiasing results with the bilinear interpolation.

The color data output from the inverse mapping block can be transformed by 3-D affine transformation and the LUT1 look-up table, resulting in constant color modulation for every pixel. The color modulation block applies individual modulation functions to each pixel. After being transformed with the LUT2 look-up table, the color data are converted into video signals.

An image processing board (Model PA99) for the projector array display was developed to implement full-size modules for the peripheral component interface bus with an analog video signal interface for input and output. This board has a maximum pixel frequency of 65 MHz that corresponds to 60 frames of XGA images per second, sufficient for medical image display.

E. Resin-Based Lens Array and Spatial Image Formation

We developed a light-(ultraviolet in this study) curable resin-based lens array for large multiprojection IV display. The light-curable resin is arranged in the shape of a discus by use of a screen stencil on a glass substrate. Since light-curable resin changes its shape to that of a convex lens with the surface tension, the
shape of the lens is stiffened when it is hit by light. To form a lenslike shape under the surface tension conditions, it is necessary to keep the discus of light-curable resin independent. To prevent light flare from the crevices between the lenses, we first masked the substrate in black ink and then printed the light-curable resin onto it. To prevent air bubbles from remaining in the positions corresponding to the mesh intersection, we placed the resin in a vacuum chamber and extracted the air bubble. This enables us to create a high-quality lens array.

The focal length of each lens is measured with an optical instrument. The measured lengths of a set of test patterns are used to precisely correct the image geometry, resulting in optimum IV image generation. For IV to work, the high-resolution, high-pixel-density image projected on the screen must be free from distortion and reflection, so an antireflective, antistatic-coated flat screen is used. It is placed at the rear of the microlens array. When a rendered elemental image of IV is projected on the screen, it is formatted as a spatial image. A diffusion sheet is placed in front of the lens array to improve image quality.

3. Evaluation

A. Device and Components

Nine projectors (XGA, U2-1110, PLUS Vision Corp., Tokyo, Japan) arranged in a 3 × 3 array (Fig. 7) display 2868 × 2150 pixels on a 241 mm × 181 mm (302.4-dots/in.) rear-projection screen. The lenses for long focus zoom lens projection include 8 sets and 12 pieces. The modulation transfer function is over 94% at 151 line pairs/in. (5.94 line pairs/mm) and over 85% at 302 line pairs/in. (11.9 line pairs/mm). We adjusted the long focus zoom lens projection to achieve three focal lengths (129.90, 107.06, 77.83 mm for positions 1, 2, and 3 separately at a wavelength of 587.56 nm), which is satisfied with different projection positions in the multiprojection system. The pitch of each pixel on the screen is 0.084 mm. Each lenslet element is hexagonal with a base area of 1.008 mm, which covers 12 pixels of the projected image. The main specifications of the multiprojection IV display are listed in Table 1.

B. Seamless Multiprojection Integral Videography Image

The adjacent projected images of the original image before calibration were brighter than other areas. Furthermore, the difference between the lens pitch and the elemental image pixel pitch caused deformation in the IV image (Fig. 8(a)). The autostereoscopic image could not be observed before correction, whereas the adjacent part of the projected images had a fatal effect on spatial autostereoscopic image formation. We obtained precise alignment information with a digital camera (Nikon D1X, resolution 3008 × 1536 pixels) and transmitted the correction parameter to the image processing hardware (Model PA99, XGA, 65 MHz, 60 frames/s, System Develop-

<table>
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<th>Setup</th>
<th>Specifications</th>
<th>Characteristic</th>
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<td>Multiprojector</td>
<td>Number of pixels</td>
<td>2868 (horizontal) × 2150 (vertical)</td>
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<tr>
<td></td>
<td>Number of projectors</td>
<td>3 × 3 = 9 XGA (1024 × 768 pixels) projectors</td>
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<tr>
<td></td>
<td>Pixel pitch</td>
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<td></td>
<td>Size of display</td>
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<td>Microconvex lens array</td>
<td>Lens shape</td>
<td>Hexagonal (microconvex lens)</td>
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<td>Lens number</td>
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<td></td>
<td>Base</td>
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<td></td>
<td>Material of lens</td>
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<tr>
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<td>Viewing angle</td>
<td>Horizontal, 16° (±8°); vertical, 14° (±7°)</td>
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Fig. 7. Multiprojection IV autostereoscopic display device: (a) external appearance, (b) configuration of nine XGA projectors and corresponding mirrors, (c) screen and projected IV image, (d) projector.
ment Laboratory, Hitachi, Ltd.). We placed the digital camera in front of the IV display at a viewing distance of 800 mm and aligned the projected images precisely in all directions using alignment information, geometric correction, and color modulation so that the display looked seamless, as if projected from a single source [Fig. 8(b)]. Furthermore, we placed a diffusion sheet in front of the display to smooth the image formation, resulting in higher-quality spatial autostereoscopic image formation (Fig. 9).

We also evaluated the spatial accuracy of the displayed image by placing a set of lattices at different depths: from 50 mm in front of the screen to 50 mm behind the screen. Figure 10 shows the lattice configuration and a photograph of a seamless IV image, illustrating the spatial geometric accuracy.

We evaluated the degree of seamlessness for different depths of an IV image for each projector by measuring the intersection of lattices between projection areas. The errors were related to the image depth. Table 2 shows the relative alignment error and standard deviation (SD) of the pixel positions between the measured and the theoretical results. Figure 11 shows spatial geometric accuracy without consideration of expansion or compression of the image depth. The spatial image accuracy of lateral and depth resolutions are discussed in Subsection 3.C.

C. Spatial Resolution Measurement

We measured the spatial resolution of displayed images using a set of black-and-white stripes, with widths from 1.0 to 4.0 mm and a spacing of 0.1 mm.18 The stripes were projected at different depths in front of and behind the display, and displayed images of the projected stripes were captured with a digital camera (Nikon D1X, 3008 × 1536 pixels). The focal length and the F-number of the camera lens are 50 mm and 16, respectively. The pupil diameter of the camera iris is approximately 3 mm, which is similar to the pupil diameter of the human eye in an ordinary environment. The resolution was determined by the minimum width at which the stripes could be clearly observed at different image depths. The spatial resolutions were measured 30 times by five people at each image depth.

Figure 12 shows an example of the IV image. The black-and-white stripes are displayed from 50 mm in front of the display to 50 mm behind the display. Figure 13 describes a mean spatial resolution for 30 measurements of real and virtual IV images. The display has a spatial resolution of approximately 1.0, 2.0, and 3.0 mm for image depths of 10, 35, and 60 mm, respectively, in front of and behind the lens array. The real IV image is superior to the virtual IV image in this display system. This is caused by a spatial deformation of IV images caused by a mismatch between the lens focus distance and the lens gap. The error between the lens pitch and the width of the element may have also caused the deformation, thus affecting the depth perception significantly on deep locations.

We also estimated the angle resolution of the images, \( \beta_{\text{max}} \) (cpr), versus viewer–image distance \( z_i \) by using Eq. (3). Figure 14 shows the observable angle resolution, both theoretical and measured, for \( L = 800 \text{ mm} \) and \( p = 1.001 \text{ mm} \). We choose the nearpoint distance of a typical eye (\( L = 800 \text{ mm} \), at which we placed the camera to record the image), which resulted in a Nyquist frequency of 399.6 cpr. This is lower than the maximum spatial frequency detectable by a typical human eye (1830 cpr).17 The resulting depth factor was 0.05. The reason for the low depth factor is that the pixel pitch of the element image is currently limited to 84 \( \mu \text{m} \) in our multiprojection system.
Although the pitch of the exit pupil and the gap are the same, the pixel pitch of the element image becomes larger in inverse proportion to the depth factor. The depth factor may be larger for display devices with higher resolution. For example, to obtain a high depth factor of 1, the pixel pitch of the element image should be 4.2 μm or smaller. Increasing the pixel density of our display system is thus a major objective.

D. Motion Parallax and Viewing Zone

The visual scene surrounding the observer is represented as a drifting image on the retinas of the observer’s eyes when the observer is moving. This relative motion of the visual image on the retinas, known as motion parallax, is used by the visual sys-

![Figure 11](image1.png)

**Figure 11.** Spatial geometric accuracy of a seamless multiprojection IV image.

![Figure 12](image2.png)

**Figure 12.** Measured IV image spatial resolution. The numbers are the image depths on the front side of (real IV image) and behind (virtual IV image) the lens array. The quadrilateral shows a real IV image of stripes projected from single projector.

<table>
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<th>Image Depth (mm)</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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tem to generate a sensation of depth. Moreover, motion parallax is often considered as being an efficient cue to generate a sensation of relative depth in cases such as superposition, perspective, shadows and shading, and luminance.

To observe a 3-D image with the correct motion parallax, one should observe it at a distance of approximately 800 mm from the system, the same as with the calibration distance of the digital camera. We used a computed tomography-scanned skull to evaluate the motion parallax of the developed IV display device. The image was generated from volumetric computed tomographic data (256 × 256 pixels times 94 slices). The results of motion parallax wherein the projected IV image was continuously observed are shown in Fig. 15. The skull could be observed clearly from different directions.

We also calculated the width of the viewing area when the viewing distance and the resolution requirement are given. The viewing area is expressed as the angle measured at the center of the display surface (the plane of the exit pupil of the lens) and indicates how long an observer can move laterally without viewing a flipped image. The viewing angle of this IV display is approximately ±8° horizontal and ±7° vertical.

4. Discussion

Our scalable multiprojection IV display system has sufficient high resolution for IV medical imaging. A long-focal-length projection technique is used to create a high-density image, thereby increasing the spatial resolution of the IV image. Digital-camera-based calibration is used to correct the geometric position and color features of the pixels projected on the screen. Image analysis is used to compute the geometric correction and color modulation needed for edge blending, enabling a seamless, uniform, multiprojection IV display. These technologies are based on the autostereoscopic image display technique originally developed for a high-resolution, scalable multiprojection display system and on a parallel synchronic display technique.

The main advantage of this high-resolution multiprojection IV display system is that it may provide a scalable method for high-resolution display, which enables the display of high-quality IV images. Since the resolution of each display panel can be increased, this technique will also offer a high-quality IV display in the future. Measurement of the spatial resolution indicated that the quality of the IV image can be improved, particularly since the current system has a
pixel density of only approximately 300 ppi. Since the spatial resolution of the projected 3-D image is proportional to the ratio of the lens diameter in the lens array to the pixel pitch of the display, the projected pixel pitch needs to be greatly reduced, and a corresponding lens array is needed. The pixel density and resolution could be increased by use of more projectors or projectors with a higher resolution (SXGA or better) and corresponding projection lenses. Greater computational power would be needed to handle the larger projection system.

The current version of the system is bulky. It must be made smaller and simpler, possibly with a design alteration of the projector and with digital micromirror devices. Such a system would be suitable for image-guided surgery and other medical uses.\textsuperscript{28,29}

An important part of our system is the technique to project high-resolution seamless images. Our system differs from a conventional multiprojection display in three ways. (1) The calibration technique used to project a seamless image is directly through the lens array. Because the quality degradation of images captured by the lens array affects the calibration and analysis, the seamless calibration technique must be improved for high-speed and precise measurement. (2) The calibration of a multiprojection image must be extremely precise because the pixels in the image must have a high density. The calibration could be improved by use of the conventional calibration technique to measure the image for color modulation. (3) It uses a different strategy for a seamless multiprojection IV image, so the calibration should be done from different positions to ensure that the lens central point is accurate, which increases the cost of calibration and analysis.

5. Conclusion

We have developed a scalable, high-resolution, high-pixel-density system for integral videography autostereoscopic image display that uses a multiple long-focal-length projection method. Testing with a fabricated large lens array designed for a scalable multiprojection display device showed that our multiprojection display system with its seamless image calibration technique has scalability that can create high-quality IV images with optional resolution.

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References


