A Calibrating Method for Projected-Type Auto-Stereoscopic 3D Display System with DDHOE
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Abstract
A new calibrating method for binocular auto-stereoscopic display system, which using digitally designed holographic optical element (DDHOE) to diffract projected light to observer, was proposed. In this method, the auto-scanning, auto-capturing, and image process were used to calibrate the DDHOE position to figure out the left eye, right eye, and non-workable lines in projection image.

1. Introduction
During the past few years, there has been a dramatic proliferation of research concerned with the three-dimensional (3D) displays technologies. By defining whether observers need to wear 3D glasses or not, they could be divided as stereoscopic and auto-stereoscopic types1-3, as shown in Fig. 1. Since stereoscopic display has congenital defects could not be resolved, such as the inconvenient and uncomfortable feeling when observers wearing 3D glasses. Therefore, auto-stereoscopic would be the following research tendency in this area.

In auto-stereoscopic 3D display, the main stream techniques are using parallax barrier or lenticular lens array on original displays with designed match pixel size. By controlling the corresponding signals of pixels, display could provide different images with binocular disparity to observer’s two eyes. According to the image function of human’s eyes, observer could combine these two images to form a 3D picture with depth information in brain4, which is illustrated in Fig. 2.

However, light efficiency would be poor of parallax barrier type5 since this system use black lines to block the useless light in wrong emitting direction. On the other hand, for lenticular lens type 3D display system6, 3D image quality has high positive relation with lens shape and performance. Additionally, digitally designed holographic optical element (DDHOE)7-9, which record and reconstruct the objects’ wavefront by using interference pattern of two coherent beams, could be assumed as natural technique and one of potential candidates for future 3D technologies.

Due to the above reasons, a new auto-stereoscopic display technique with DDHOE was designed to solve these shortcomings, as shown in Fig. 2. In this design, the signal output pattern is similar as polarizing type technique of stereoscopic display. To achieve glasses-free purpose, light of odd line pixel could be controlled to focus in left eye position by holographic diffraction and vice versa.

1. Schematic diagram of floating 3D display system.
2. Schematic diagram of proposed 3D HOE system.

2. Binocular 3D Display System with DDHOE
For the new type auto-stereoscopic display system, we designed and manufactured a DDHOE10,11 as the optical screen, which was made by photo polymer sheet, and has three types of compensation functions at the same time. The new designed functions of DDHOE are explained in the following.

First, DDHOE should have a compensated function to solve the projection angle issue since a real projector has such projected divergent angle, which would induce that the received light in DDHOE screen was not the same as assumed plane wave from the projector, originally.

Second, DDHOE should be designed to have function of stereo vision generation, which could converge signals of different eyes separately. In the design case, lights would be diffracted to converge on left eye or right eye location of observer, which separated with each other as 62 mm in horizontal direction, based on the different vertical positions.

Third, since some portion of the projector’s light would be directly reflected at glass or polymer surface of DDHOE, the directly reflected light may be received and obstruct for the observers. Therefore, the direct reflection and designed diffraction angle should be controlled as spatially separated by changing vertical angle of the diffraction in DDHOE to remove interference issue.

In summary, the micro-concave mirrors of DDHOE screen have functions of generating stereo vision,
projector-compensation, and hinder suppression, where the specification is listed in Table 1. By projecting the stereo images onto the screen, 3D scenes would be displayed.

Table 1. Specification of DDHOE and 3D display system.

<table>
<thead>
<tr>
<th>HOE and System</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>100.44mm x 100.44mm</td>
</tr>
<tr>
<td>Pixels for HOE</td>
<td>284(V) x 142(H)</td>
</tr>
<tr>
<td>Projector distance</td>
<td>418.5mm</td>
</tr>
<tr>
<td>Viewing distance</td>
<td>910.0mm</td>
</tr>
<tr>
<td>Function</td>
<td>Stereo view</td>
</tr>
<tr>
<td></td>
<td>(Odd lines=R; Even lines=L)</td>
</tr>
<tr>
<td>Stereo vision generation</td>
<td>±6.81°−0°(center)</td>
</tr>
<tr>
<td>Projection angle</td>
<td>62.0mm separation</td>
</tr>
<tr>
<td>compensation</td>
<td></td>
</tr>
<tr>
<td>Diffraction direction</td>
<td>300mm above the HOE</td>
</tr>
<tr>
<td>Micro-pixel size</td>
<td>352.8μm(V) x 705.6μm(H)</td>
</tr>
</tbody>
</table>

3. Calibration Method

To build the 3D glasses-free system, first of all was to set up all hardware, which consists of DDHOE, projector with 4K resolution, white screen, camera, circuit board, computer and laptop. In the system, computer was connected with projector to commend the output signal and projected image. The white screen was used to reflect the diffracted light to test the DDHOE’s functions. Moreover, the circuit board was used to control camera shutter, which would take the photos and save them in laptop. Fig. 3 depicts the proposed new 3D display system and the equipment for calibration. All experimental components would be set on the optical table to remove the vibration issue.

3.1 Setting System

At first, the relative positions and angles, α, β and γ, between projector and DDHOE should be corrected as precisely as possible by hand, as shown in Fig. 4(a). According to the design, the horizontal distance along z axis should be set as 418.5mm in Table 1. In addition, the location in x and y axes of system could be registered by moving projector to check full projected image was inside the DDHOE, which was fixed in optical rail.

For α axis, it could be easily set as 0° as original designed. Since the size of SONY projector is huge, it should be checked that the diffracted light from DDHOE would not be blocked by projector. For β axis, it would be rotated to control two focus points locating at suitable observer positions by ejecting full green image on projector, as shown in Fig. 4(b). For γ axis, after ejecting horizontal line from projector, the diffracted light on white screen should be controlled as horizontal ellipse without distortion by rotating on this axis, as Fig. 4(c) shown.

3.2 Projection of Calibration Patterns and Detection of Diffracted Light

Since DDHOE was designed with new functions for auto-stereoscopic display, it could be divided as left eye, right eye and non-workable regions, which should be distinguished by calibration. In the scanning and capturing processing, after diffracting from DDHOE, light would be focus as two spots on the white screen when the projected signal was full green image, which was defined as reference photo. Moreover, computer connected with circuit board, which consist of Arduino board, circuit board, power charging cable, USB line and camera remote switch, to control camera shutter linked a laptop to save the photos. By using the computer and designed circuit board, the scanning horizontal lines and camera shutter could be controlled by program coding in the computer automatically. The detail specification of scanning and capturing processing would be shown in Table 2.

Table 2 Specification of scanning and capturing system

Fig. 4. Setting method of relative angles, α, β and γ.
3.3 Image Processing to Detect Left and Right Diffracted Regions

After capturing the diffracted light photos, the image processing would be used to distinguish each line of signal belong to which region, left eye, right eye, or non-workable. The first step of image processing was to load the reference image, which projected signal was full green. By defining the threshold value of green gray level in the photo, the signal diffracted regions, for left and right eyes, on white screen could be figured out. In the following photos, only these two regions image should be considered, which could improve the system calculation speed significantly.

The second step was to pick up one captured photo with special case, which included diffracted light and unnecessary direct reflected light on the white screen, as shown in Fig. 5(a). By using two masks of the first step and just use green signal, the results would be shown in Fig. 5(b). In addition, the function

\[
\text{New image} = G_{\text{gray level}} - \left( \frac{R_{\text{gray level}} + B_{\text{gray level}}}{2} \right),
\]

was used to evaluate reflected environment white light, which was assumed as noise, as shown in Fig. 5(c).

Third, the threshold value was hardly chosen to separate the required signals and direct reflected light since the brightness of some signals was weaker than the direct reflected light, as shown in Fig. 5(d). Therefore, the new method used the vertical line, which located at the center of left and right refracted areas, to detect the noise positions and values, as shown in Fig. 5(e). By subtract the maximum value of unnecessary direct reflected light in the corresponding vertical positions of left and right diffracted regions, the necessary signals and direct reflected noise could be extracted, as shown in Fig. 5(f).

3.4 Redrawing Output Signals

After analyzing the workable region of DDHOE, the output signals of left and right eye regions could be recognized. Since the final output image should have a good quality and low crosstalk, the judge equations would be defined strictly. By analyzing the pixels map in output signals image, there had three main reasons to induce the non-workable region. First, vibration or machine’s error of DDHOE printing would cause some defects on the screen. Second, at the boundary region, the projected signals would cross both eyes’ region since the projected horizontal light would be diffused. Third, since the system was set roughly, the rotated angle, γ, of DDHOE would not be horizontal perfectly, which would induce some boundary area could not be used.

By building all items in the commercial software and placing them at the different space and depth position, two different viewing angle images with parallax of objects could be redered from 3D graphics software. Based on the look-up-table of calibrated results, these two images could be redrawed as suitable output signals for proposed system, as shown in Fig. 6. Furthermore, the specifications of proposed system in classification and redrawing output signals would be listed in Table 3.
4. Results and Discussions

After completing the calibration and redrawing output signals, the designed image would be projected by projector on DD HOE to display the auto-stereoscopic image. In the proposed system, observer could watch 3D image when standing in the suitable position. To determine the image quality of this system, the signals of left eye and right eye were projected separately. In addition, observer could use one eye to watch the other eye’s signal to check whether there had ghost image or not, and vice versa, as shown in Fig. 7 and Fig. 8.

According to the designed image processing, there would not have any crosstalk in this system. However, the ghost images could still be detected in Fig. 7 (b) and Fig. 8 (a). The main reason of this issue was that the brightness of leakage light was too weak. The camera was difficult to capture the leakage light when the projector projected horizontal lines. But when the ignored leakage light of each scanning image combined with each other, observer could detect the crosstalk value and see the ghost image.

Moreover, to check whether the functions of DDHOE were the same as designed, the fog machine, Antari Z-800II, was used to detect the light paths of this system, as shown in Fig. 9 (a). Due to the results in Fig. 9 (b), after ejecting from projector, light paths could be divided as three different directions. The first and the second paths were transmitted light and zero order diffraction, which was reflected directly and non-usable in the system. In addition, the third one was the first order diffraction designed to use in the new proposed auto-stereoscopic system. Moreover, the color of diffracted light would be a little bit different with the projected light, since DDHOE just has the workable function for the special wavelength of light. Furthermore, the diffracted light path would also be checked when the projected signals were on the conditions of both eyes, left eye and right eye, as shown in Fig. 9 (b), Fig. 9 (c) and Fig. 9 (d).

5. Conclusions

In this paper, a calibrating method for binocular projection type auto-stereoscopic display system, which consists of a projector and a DDHOE plate as focusing mirror array, was proposed. By projecting the designed image with calibration on the DDHOE plate directly, the observer could see the reconstructed 3D image from the same side as projector.

To calibrate the DDHOE with new functions, a setting system method, an auto-scanning and capturing
system, an image processing for distinguish, and a redrawing calculation were completely finished. In addition, the experimental results showed that the reconstructed 3D image had a good image quality and a low crosstalk.

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**References**