3D Display | 3D Image | Mobile Device

Technology Reports

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Mobile 3D Display Technology to Realize Natural 3D Images

A hot topic in recent years has been the successive releases of 3D movies. Amid growing expectations for 3D capable mobile devices, NTT DOCOMO have prototyped a high-density directional images method for mobile 3D display. Considering the needs for compact size, realistic replay and a wide viewing space, the prototyped display has the characteristic that perceived images change according to the movement of the observer's head or the angle of the display, which is something that conventional 3D display technology cannot achieve.

The technology makes it possible to present 3D images suited to mobile environments, and gives the observer the perception that they are actually holding real objects in their hand.

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1. Introduction

Nowadays, as a new method of cinematic expression continuing from the high resolution developments like HDTV images, 3D movies are offering more and more promise. Especially in the cinema, more movies are being shown in 3D. This is because the high quality content is realized through large capital investment, the added value of 3D movies can more effectively draw movie-goers since they cannot enjoy such content at home, and 3D representation can help prevent secret filming—a problem that has afflicted the movie industry for years. The number of 3D-capable cinemas is also on the rise, meaning we have entered the stage of genuine 3D movie popularization. The advanced sense of presence and immersion that 3D movies offer puts them in a completely different class from traditional 2D movies. As well as being adopted for cinema, in anticipation of the high added-value of 3D and potential for improved advertising effectiveness, 3D displays are being installed more and more often into non-mobile devices such as household TVs and digital signage*1, and into mobile devices such as mobile phones.

NTT DOCOMO is conducting 3D

*Front cover 3D display image courtesy of ROKKON Inc.

*1 **Digital signage**: Advertising media using digital technology. Using displays or projectors to change advertising content in response to time or location, this technology is gaining attention as an alternative to conventional advertising media such as posters etc.

display research with the aim of realizing environments enabling 3D images enjoyment anywhere, any time[1]. We are continuing to examine 3D display technologies suitable for mobile environments focusing on the differences compared to the non-mobile displays used in cinemas and TVs. Specifically, unlike non-mobile 3D displays, we are researching technology that characteristically does not require the observer to wear glasses to perceive the 3D image, that can effectively display 3D images even on small screens, and that realizes applications specialized for "handheld" mobile environments.

In this article, while comparing with non-mobile displays such as domestic TVs and cinemas, we describe mobile type 3D display technology using the high-density directional images method. We also describe our prototype displays, and the results of objective evaluation by optical measurement to illustrate their potential.

2. Requirements for 3D Image with Mobile Devices

2.1 The 3D Images Market

3D is grabbing attention as the next-generation cinematic expression next to HDTV. Research organizations including universities, appliance and display manufacturers, are going full steam ahead with 3D display technology R&D. The recent rise of 3D games and movies is evidence that the new 3D market is becoming properly established.

Also, advances in high-speed, high-capacity wireless technology and high-functionality mobile devices capable of receiving One Seg content etc., mean that large data content including movies and digital broadcasts can be viewed even on mobile phones. With all these advances, it's very easy to conceive of a new 3D mobile device market in the next-generation of image expression. However, image media for mobile devices differs from cinemas or household TVs, because the viewing environment is quite different, and the applications are not the same.

2.2 Features of the Mobile Environment

One of the biggest features of the mobile environment is size constraints. Viewing environments that use large-sized screens like cinemas are able to give the viewer a sense of immersion into the expanse of the scene, an effect which can be expressed at an even higher level of realism with 3D images. Currently, the main type of 3D display method used with the comparatively large-size TV and cinema displays etc. requires the viewer to wear glasses that use polarizing filters[*2] or liquid crystal shutters. In these display methods, to simultaneously display a 3D image to all of the viewers, the same scene is displayed to multiple viewers regardless of the viewing position. However, because of the screen size limitations in mobile environments, it is difficult to recreate a similar sense of sinking into the scene.

2.3 Requirements for 3D Displays Suitable for Mobile Environments

In a mobile 3D environment for reasons already stated, rather than try to recreate the sense of actually being inside an expansive scene, as is possible with large-screen image display, we think it's more important to express, for example, a sense of the detailed reality of objects or the texture of materials, by creating the perception that objects are right in front of the viewer, and closer to their actual size. The phenomenon of the changing appearance of a 3D object when viewed from different positions is known as "motion parallax[*3]," and is one of the principal factors that enable people to see 3D objects. Motion parallax allows human beings to appreciate textures such as the surface of water or the sparkling of jewelry; however, large-screen 3D displays that require glasses cannot recreate motion parallax.

Bearing in mind these features and characteristics, we will sort out the requirements assumed for mobile 3D display. Firstly, since mobile devices are usually handheld, there are physical limitations to the size of the whole hardware package, not only the screen size. Secondly, in mobile usage environments the viewer is also close to the display and distance and position can

*2 **Polarizing filter**: A filter that allows light to pass or blocks it depending on its polarization. Some existing 3D displays use polarizing filters in the form of 3D glasses to enable projection of different images to the left and right eyes.

*3 **Motion parallax**: One of the factors that enable human beings to recognize 3D objects. This gives the effect of changing object appearance when the viewing position changes. Other factors include binocular parallax that enables human beings to perceive 3D objects by presenting different images to the left and right eyes.

be easily changed. Thirdly, there is a need to recreate the realism and texture of objects, even with a compact display.

3. 3D Display Methods that Satisfy Requirements

3.1 High-density Directional Images Method

Due to the screen size limitations mentioned, mobile 3D displays must be compact. When we considered what type of 3D display system would satisfy this requirement, we decided the high-density directional images display method was suitable because it allows for a compact and thin configuration.

The high-density directional images display method displays the 3D image to the viewer by simultaneously displaying multiple images. In contrast to conventional 3D display methods that rely on stereoscopic projection of two different images for the left and right eyes, this method recreates motion parallax, thus enabling the image to change depending on the angle of the viewer's head or the tilt of the display[2]. This is done by attaching a lenticular lens[*4] diagonally across a high-resolution Liquid Crystal Display (LCD) to achieve high-density directional image in the horizontal direction. This principle is shown in **Figure 1**.

The lenticular lens on the surface of the LCD controls the direction of the light emitted from each pixel, causing the light to be only visible from certain angles. Because there are multiple pixels behind the lenticular lenses, the viewer sees different images depending on the viewing angle. Since the system creates an image that is equivalent to looking at an actual object from the same angle, it effectively displays images for the left and right eyes, which means the viewer doesn't have to wear a device like 3D glasses, and thus makes it possible to reproduce more natural-looking 3D images. High-density directional image enables a finely detailed image display for the multiple viewpoints separated by intervals even as small as 1 degree. This is how this system can achieve smooth motion parallax even with tiny changes to the image viewing position.

3.2 Characteristics of the High-density Directional Images Method

The LCD and lenticular lens combination for this method is very easy to configure. Also, since the method allows for high-density display of directional images, it can recreate smooth motion parallax needed to express substance and texture such as the sparkling of jewels, the reflection of light off water surfaces, or the smoothness of fabric[3]. Moreover, the high-density of intervals displaying directional images means that the viewer simultaneously sees multiple directional images. This enables "accommodation" (the ability of the eye to stay focused on an object as its distance changes), and thus produces a more natural-looking 3D dis-

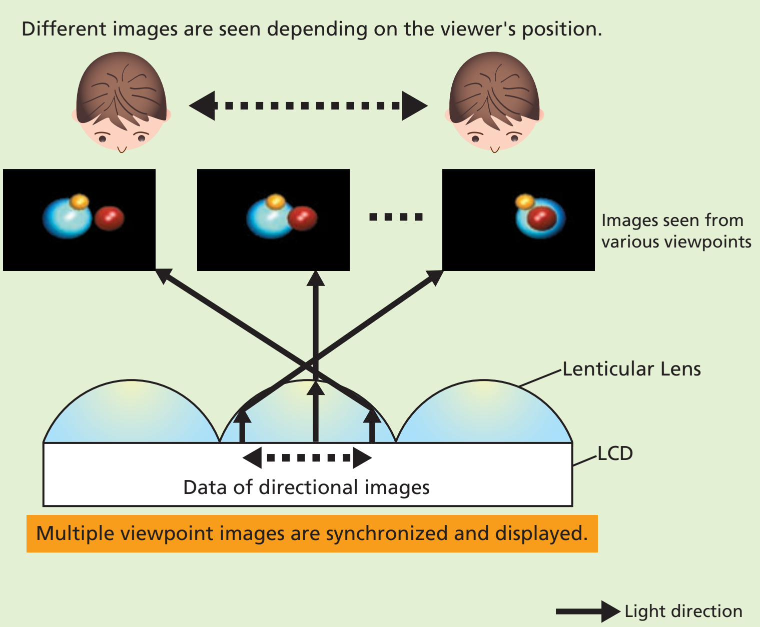

Figure 1 High-density directional display

*4 **Lenticular lens**: An array of cylindrical shaped lenses. Cylindrical lenses only act as lenses in the horizontal direction, and are effectively the same as an ordinary sheet of glass in the vertical direction.

play[4].

We believe these characteristics satisfy the aforementioned requirements for 3D displays in mobile devices. Firstly, the simple hardware configuration gives good compatibility with existing devices, and satisfies the need for compactness. Secondly, faithful reproduction of objects is simple thanks to the smooth motion parallax and textural expressiveness that more realistically reveals the details of displayed objects. Thirdly, because 3D images can be viewed from a wide viewing zone, there are fewer limitations to viewing distance and position.

The following describes smooth motion parallax and the wide 3D viewing zone in more detail. If we focus on the directional image emulating from one point on the display, the viewer sees a part of the directional image divided into rectangles in the vertical direction (**Figure 2**). Similarly, when the display is viewed from a different position, part of a different directional image divided into rectangles appears.

The viewer sees the whole display as combination of these directional images divided into rectangles.

3.3 Metrics

As already mentioned, the main feature of high-density directional images display is that the image projected into the viewer's eyes is a combination of rectangular images that realizes smooth motion parallax. However, as a result of viewing combined multiple images, luminosity unevenness occurs due to the overlapping at the borders of the rectangular directional images. Therefore it is important to inspect and evaluate the luminosity unevenness for a high-density directional images 3D display.

Here, Moiré*5 striping, which also occurs in the lenticular lens display, has been proposed as a metric for evaluation of stereoscopic display methods[5]. However, the Moiré effect proposed as an evaluation index is a result of the periodicities of the lenticular lens and the pixels in the LCD panel and it is different to the luminosity unevenness mentioned above. Therefore for high-density directional images displays, it is important to evaluate the luminosity unevenness separately from the so-called Moiré effect.

4. Mobile 3D Display Prototype and Evaluation

4.1 Lenticular Lens Design

For the mobile 3D displays, we used the three 7.2 inch , 4.5 inch , 2.5 inch sizes for the LCD panels, and designed lenticular lenses based on these panel specifications.

The specifications for the three types of panel used in the prototypes are shown in **Table 1**.

Attaching a lenticular lens diagonally to these panels achieves the high-density directional images display. Firstly, to achieve a certain level of motion parallax, a viewing distance and

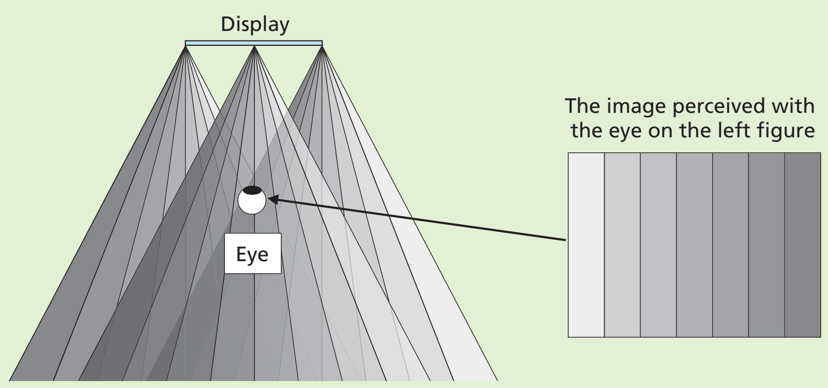

Figure 2 Perceived image

Table 1 Specifications of LCD panel

Screen size (inches)	7.2	4.5	2.5
No. of horizontal pixels (pix)	1,280	1,024	480
No. of vertical pixels (pix)	768	600	690
Pixel density (ppi)	207	265	332

*5 **Moiré**: A new striped pattern emerging from overlapping well-ordered striped patterns, due to differences in periodicity between the stripes.

the viewing space were assumed. The area in which the directional images were presented was decided based on these assumptions. Here, a viewing distance was decided as 300 to 400 mm from actual experimentation with a mobile terminal. The viewing space was set at 200 to 250 mm to ensure that even if the viewer moves the distance equal to the size of their head, they will not be outside of the viewing space. The decided parameter values are shown in **Table 2**.

In the cases of the 7.2 and 4.5 inch panels, to achieve smooth motion parallax, the number of directional images was set to 30 in order to make the pitch of directional images approximately 1 degree. In contrast, in the case of the 2.5 inch panel, because of the comparatively lower number of pixels, the pitch of directional images was approximately 1.54 degrees as a result of setting the number of directional images to 24 to make both the vertical and horizontal pixels for the 3D image more than 100 pixels.

Lenticular lenses were designed according to these parameters settings. The lens designs were optimized to reduce chromatic aberration*6 as much as possible.

4.2 Display Prototype

Figure 3 shows the prototyped display, to which a custom-designed lenticular lens is attached. The results are taken from different angles for the various displays, and because the image changed from different viewing positions and it can be seen that motion parallax was achieved. **Photo 1** shows

Table 2 Designed parameters of 3D displays

	7.2 inch	4.5 inch	2.5 inch
Assumed viewing distance (mm)	400	400	300
Viewing space (mm)	200	250	200
No. of directional images	30	30	24
Viewing angle (degrees)	28.07	34.71	36.87
Pitch of directional images (degrees)	0.94	1.16	1.54
No. of horizontal pixels of each directional image (pix)	256	200	120
No. of vertical pixels of each directional image (pix)	128	100	115

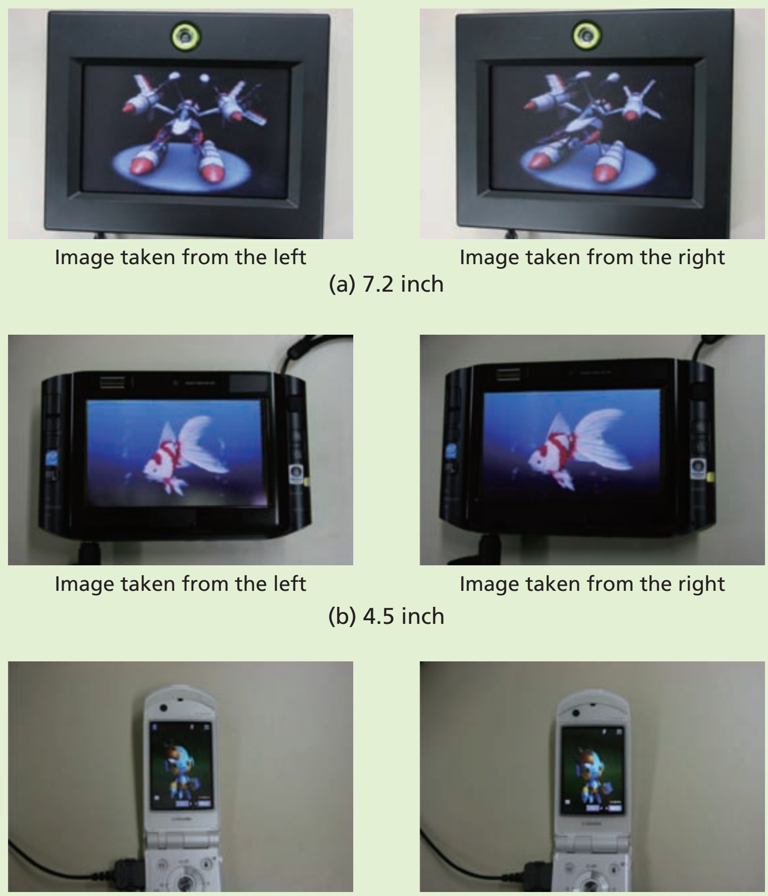

Image taken from the left / Image taken from the right

(a) 7.2 inch

Image taken from the left / Image taken from the right

(b) 4.5 inch

Image taken from the left / Image taken from the right

(c) 2.5 inch

Figure 3 Prototype displays

*6 **Chromatic aberration**: Unsatisfactory lens performance caused by different refractive indices for different wavelengths of light due to the material from which the lens is made. This article describes how chromatic aberration was minimized as much as possible by optimizing for red, green and blue colors emitted from the LCD panels.

one image from among the 30 images used for directional imaging with a 4.5 inch prototype display, with the remaining 29 images not displayed. Photo 1 shows that only one image is displayed in a limited area, and that the viewer sees a combination of multiple images.

4.3 Evaluation by Optical Measurement

The prototype displays were evaluated with optical measurements. As described in Chapter 3, luminosity unevenness is a particularly important factor in viewing multiple directional images simultaneously with 3D displays using high-density directional image. Luminosity unevenness was evaluated by measuring the luminance distribution on the prototype display screen. The measurement was taken for a single directional image in a completely white state (RGB values were set to 255), with the other directional images black (RGB values were set to 0) and the luminance measured for each illuminated directional image. As an example, results for the 7.2 inch prototype display are shown in **Figure 4**. The horizontal axis of the graph represents the angle from the front of the display, and the vertical axis represents normalized values of luminance set to a maximum of 100.

As seen in Fig. 4, some luminosity unevenness occurs, although the level of this unevenness is within 10% of the overall luminosity distribution, which is not a practical problem. Luminosity unevenness for the 4.5 and 2.5 inch prototype displays was even lower than the 7.2 inch display.

5. Conclusion

Since there is a difference in viewing environments and applications with mobile device displays compared to non-mobile displays such as cinemas and household TVs that can guarantee a comparatively large display area, we designed and built prototype 3D displays using the high-density directional images method to satisfy the requirements for mobile 3D image that we had studied and defined. This prototype display has a good compatibility with existing mobile devices, is capable of a wide viewing area, and because of its smooth motion parallax, it is capable of displaying natural 3D images that fulfill the requirements for a mobile environment. The displays' luminosity unevenness was also evaluated objectively using optical measurements. The results confirmed that the luminosity unevenness that occurs does not present any practical problems.

With further subjective experimentation and evaluation using the prototype displays, we aim to achieve 3D display more suitable for mobile environments.

Photo 1 Directional image

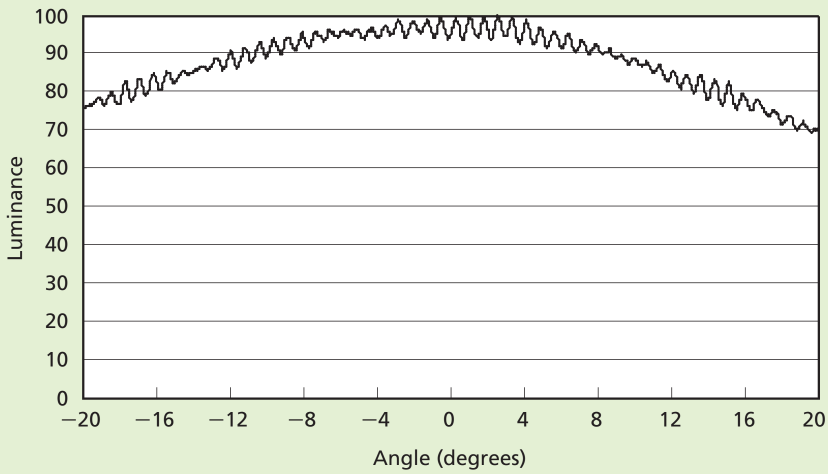

Figure 4 Results of optical measurements

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