integral imaging can be understood as the number of different pixel data within a certain viewing angle. The angular resolution is determined by the number of pixels on the flat-panel display for a single elemental image, and thus it is limited by the finite pitch of pixels on the flat-panel display. When the other viewing characteristics are fixed, either more pixels or a higher-resolution flat-panel display are needed for the higher angular resolution.

3.3 Implementation of a Lenticular 3D Display

Figure 3.10 shows the general process for implementing a lenticular multi-view display. In practice, the lenticular multi-view display is implemented by combining the array of cylindrical lenses and flat-panel displays, such as LCDs and OLEDs. The specifications of the cylindrical lens and flat-panel display determine the viewing parameters of a lenticular multi-view-display system. Therefore, it is important to analyze the relation between the specification of the lenticular lens and display device and the viewing parameters for manufacturing the lenticular multi-view display. The latter can be derived from the relation between the viewing parameters of the multi-view display and the optical properties of the lenticular lens, as explained in Section 3.1. Unfortunately, the molding process for a lenticular sheet has a high cost. Lenticular lenses with a similar specification calculated by theoretical equations are used in the following examples. In general, the major specification of the lenticular lens is defined by lens per inch (LPI), i.e., how many lenticules are arranged in one inch and represent the pitch of the lenticule. The lenticular lens is manufactured to have a focal length that corresponds to its thickness. Figure 3.11 shows the commercialized lenticular lenses that have a LPI of 25, 40, and 75. There are also various kinds of

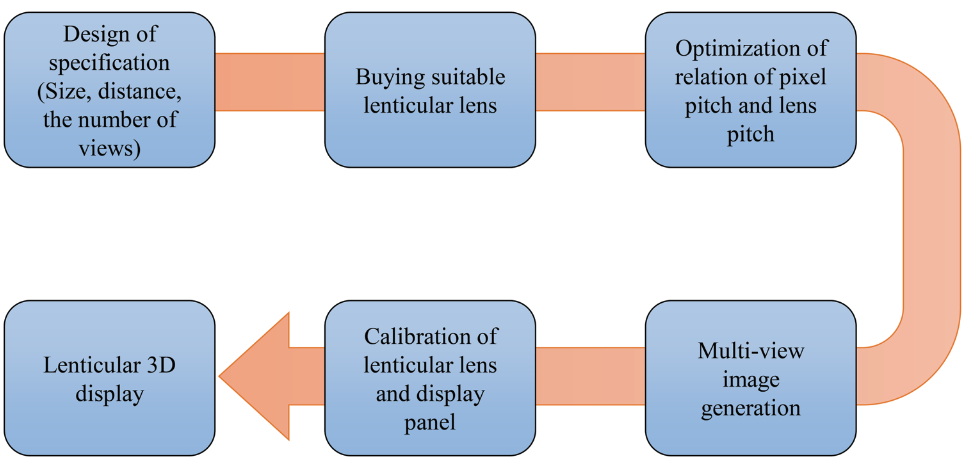


Figure 3.10 Process of the fabrication of lenticular multi-view display.

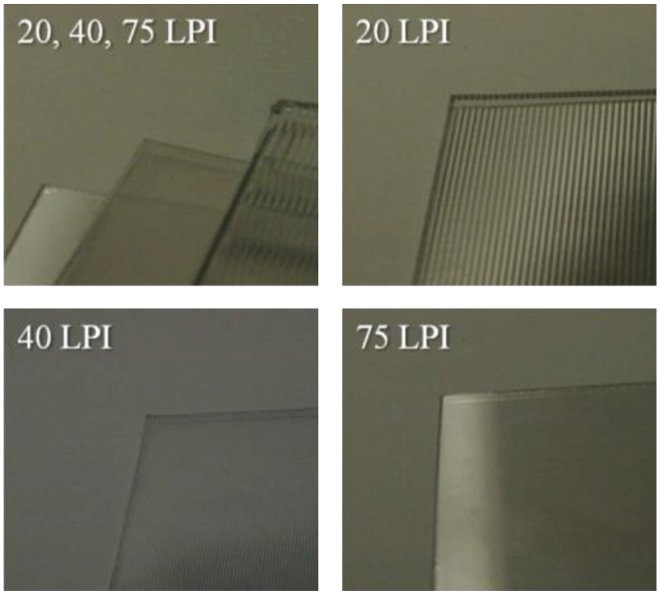


Figure 3.11 Captured images of commercially available lenticular sheets (20, 40, and 75 LPI).

lenticular lenses commercially available, the detailed specifications of which are provided in Table 3.1.[15]

The optimum viewing distance of a multi-view system is calculated by

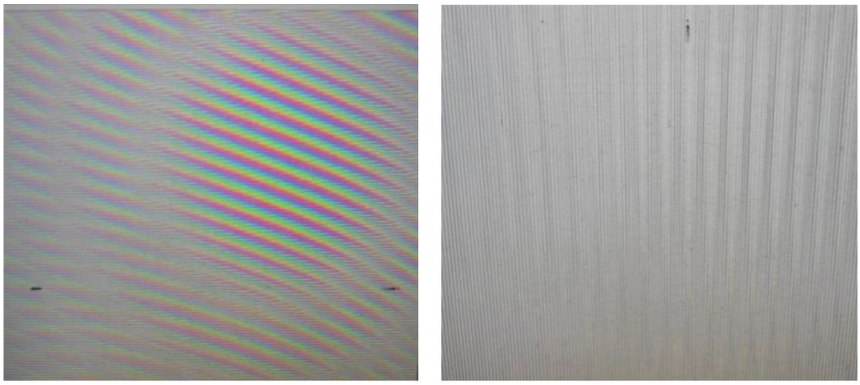
$$D = f\frac{Np_p}{Np_p - p_l}, \tag{3.19}$$

where N is the number of views, p_p is the pixel pitch of the display, p_l is the pitch of the lenticule, f is the focal length of the lenticular sheets, and D is the optimum viewing distance.

In order to implement a prototype of a multi-view display using a lenticular sheet, a LCD display that has a size of 24 in., a resolution of 3840×2400, and a pixel size of $124.5\,\mu\text{m}$ is used. The desired viewing

Table 3.1 Specifications of commercially available lenticular sheets from one particular manufacturer.[15]

LPI	Thickness (in.)	Lenticule Width (in.)	Viewing Angle (deg.)
40	0.0330	0.0251	49
50	0.0240	0.0200	54
62	0.0270	0.0161	42
75	0.0180	0.0133	49
100	0.0215	0.0101	31
100	0.0140	0.0100	47
150	0.0103	0.0067	43



(a) (b)

Figure 3.12 Moiré problem in the lenticular type multi-view display: (a) with moiré (b) without moiré.

parameters of the prototype are the seven views with an interval of views corresponding to a binocular distance of 65 mm. The lenticular sheet with a 3.2-mm focal length and a LPI of 25 is chosen to get the desired specifications. The parameters of the prototype are calculated by the above equations, and the prototype has an optimum viewing distance of 1433 mm, an effective pixel pitch of 145.5 μm, and a gap between the display and lenticular sheet of 3.2 mm.

As shown in Fig. 3.12(a), the lenticular-lens multi-view display has a moiré pattern problem that also appears in the parallax-barrier multi-view display. The moiré pattern in the multi-view display is due to the interference created by the stacked pair of 1D periodic structures: a lenticular lens (or parallax barrier) and a sub-pixel structure of LCD. The moiré pattern can be eliminated simply by placing the lenticular lens perpendicular to the sub-pixel structure of a LCD and lenticular sheet, as shown in Fig 3.12(b). The moiré pattern problem will be solved by the slanted lenticular method (see Chapter 4).

The next step involves arranging the lenticular sheet on a LCD. A calibration pattern is used for this process. In the example system, the calibration pattern is composed of four black and one white view images. The white view image is usually located at the center as shown in Fig. 3.13. Figures 3.14(a) and (b) show the captured images of the prototype after calibration at the optimum viewing distance of 1433 mm and out of the optimum viewing distance, respectively. At the optimum viewing distance, the calibration pattern is observed in the entire effective display area. On the other hand, the calibration pattern forms a white stripe when the prototype is observed out of the optimum viewing distance. Away from the viewing distance, the observed pixel area in the base image is increased compared to

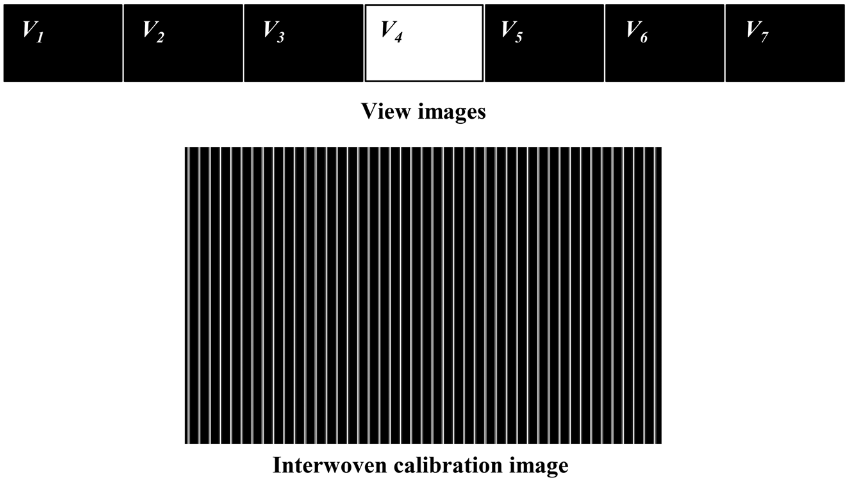


Figure 3.13 View images and the interwoven calibration image.

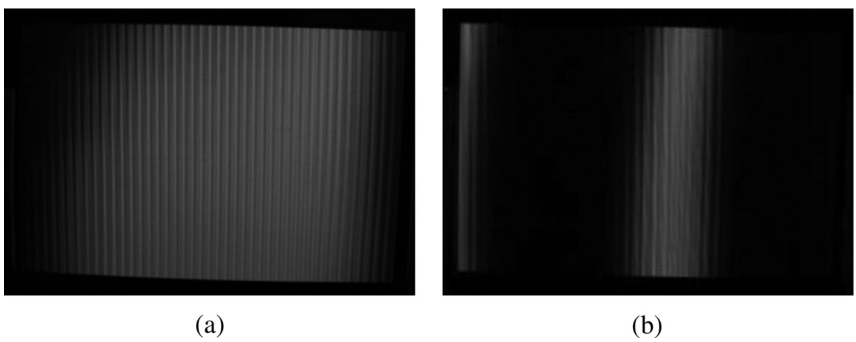


Figure 3.14 Captured images of calibration patterns (a) at one viewpoint and (b) out of the viewpoint.

the optimal condition, resulting in a different sampling period.[16] This phenomenon occurs because the sampling distance of the view image depends on the viewing distance, as explained in Section 3.1.

Figure 3.15 shows the implemented lenticular multi-view-display prototype. After rotating the LCD display to solve the moiré pattern problem, the lenticular sheet is attached to the display surface with a calibration process, whereby the optimal lens position and viewing distance are found. In order to inspect the generation of each view image from the prototype, the base image representing the seven different views is calculated by the mapping method described in Section 3.3. The base image used in the experiment appears in Fig. 3.16, and each view image captured in a different viewing position appears in Fig. 3.17.

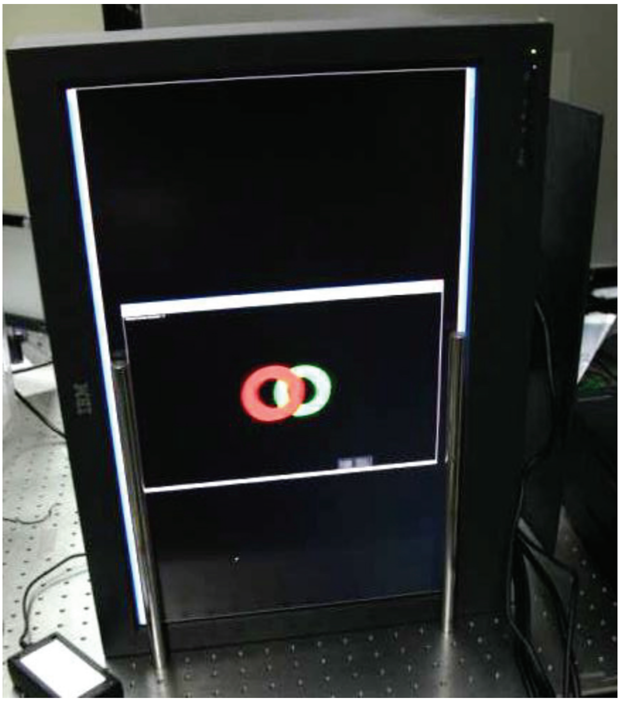


Figure 3.15 Captured image of implemented lenticular multi-view-display prototype.

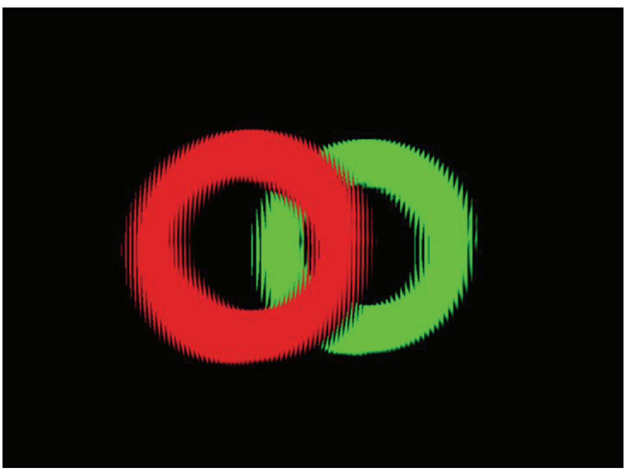


Figure 3.16 Base image for the implemented lenticular multi-view-display prototype.

3.4 Implementation of a Parallax-Barrier Display

The parallax-barrier multi-view display is a representative multi-view-display method;[1,2] its simple configuration provides flexibility to the choice of specifications. Parallax barriers can be made of passive devices, such as