Autostereoscopic Displays for Healthcare Applications

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Abstract

(Auto)stereoscopic displays are increasingly being used in healthcare applications such as radiology and surgery. This paper discusses basic operating principles of (auto)stereoscopic display technology, with special attention for recent switchable 3D technology that allows for switching between 2D and 3D mode of operation.

Important image quality metrics such as crosstalk, (true) 3D resolution, brightness etc. and usability aspects (eg. glasses free, 3D viewing zone) are considered in context of applications in radiology and surgery.

Finally, an outlook is given to future applications in healthcare and drivers and blockers for broader adoption of (auto)stereoscopic displays in healthcare are discussed.

Author Keywords

Display; 3D; Autostereoscopic; Healthcare

1. Introduction to (auto)stereoscopic displays

Stereoscopy involves presenting two slightly different images with horizontal disparity separately to the left and the right eye. These two-dimensional images are combined in the brain to give the perception of depth.

Conventional stereoscopic displays typically make use of polarization filters or active glasses. Polarization filters in stereoscopic displays [1-2] create a stereo-interlaced image by stacking left and right image pixels in alternating rows (Fig. 1(a)). These pixels are then projected through polarizers, that can be either circular or linear, with an opposite direction for the left and right views. Users wear polarized glasses to filter the perceived image, where the left lens is equipped with a polarizer matching one direction, and the right lens with a polarizer matching the opposite direction, for instance a horizontal and vertical one. This setup ensures that each eye only sees the intended left or right image, creating a stereoscopic effect for the viewer.

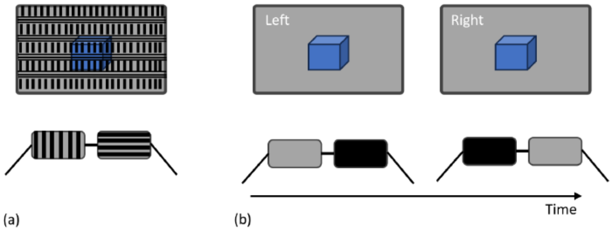

Figure 1. Polarized (a) and active shutter (b) stereoscopic displays

Active stereoscopic displays [1] show the left and right images time sequentially with high frequency (Fig. 1(b)). The user needs to wear shutter glasses that are synchronized with the display. When the left image is displayed, a filter blocks the right eye from seeing it. Then the right image is displayed, and a filter blocks the left eye. Since this is done at a very high frequency the human brain is able to combine these two images to a single 3D image.

Autostereoscopic displays enable glasses-free three-dimensional visualization, omitting the need for wearable equipment. Autostereoscopic displays utilize an optical layer (laminated) in front of the display panel to project distinct left and right images directly to the viewer's eyes. The two main types of optical layers are parallax barriers and lenticular lenses [1-2], as shown in Fig. 2. Parallax barriers incorporate a series of precisely positioned slits or barriers to separate the views. Lenticular lenses consist of an array of cylindrical lenses that projects the light of each pixel of the display panel such that the left image pixels end up in the left eye, while the right image in the right eye.

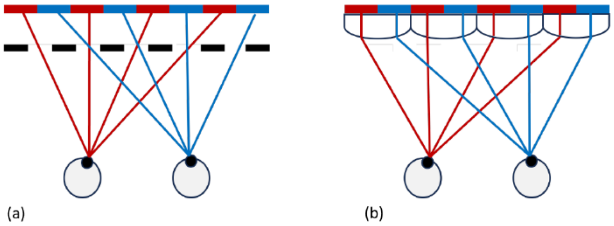

Figure 2. Autostereoscopic displays using (a) parallax barrier or (b) lenticular lens technology

Autostereoscopic displays can be designed for both multi-viewer and single-viewer applications [3]. The main limitation of a single-viewer autostereoscopic display is that only one person can see the 3D image. In multi-view displays, several individuals can simultaneously observe 3D the content from typically fixed viewpoints.

An important parameter for any 3D technology is the perceived resolution [3] which determines the perceived quality of the presented image. Given a base panel with given resolution, the perceived resolution of an autostereoscopic displays is inversely proportional to the number of viewpoints [3].

2. Switchable autostereoscopic displays

In the case of switchable autostereoscopic displays the 3D display features a lenticular lens sheet affixed to an LCD panel [4]. The lenticular lens sheet comprises a series of narrow, elongated lenses, often applied at a slant. These lenses project visual content in multiple directions, alternately displaying images for the left and right eyes. This mechanism is depicted in Figure 3.

The lens itself is switchable. A switchable lenticular lens is a type of lens that can switch itself on and off. This is typically achieved by using liquid crystals or other materials that can change their refractive index when an electric field is applied (see Figure 4).

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When no electric field is applied, the liquid crystal molecules are in a default orientation that allows light to pass through the lenticular lens without significant focusing. This results in a 2D image where the lenticular lens effect is effectively "turned off." When a voltage is applied across the electrodes, the electric field causes the liquid crystal molecules to reorient themselves. This change in orientation alters the refractive index of the liquid crystal layer. As a result, the light passing through the lenticular lens is focused in specific directions, creating a 3D effect or multiple views. The lens is now in its "on" state.

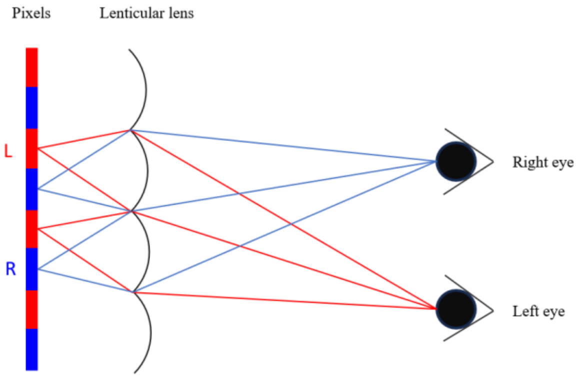

Figure 3. The principle of a lenticular lens 3D display. The lens projects the left/right pixels to respectively the left/right eye

A tracking solution aligns the left and right viewing lobe with the respective left and right eye. The left lobe exclusively contains pixels for the left image, while the right lobe contains pixels for the right image. These images present slightly different perspectives of the scene, mimicking the binocular disparity that occurs in natural 3D vision. The brain then combines these different perspectives, creating the perception of depth and forming a three-dimensional image.

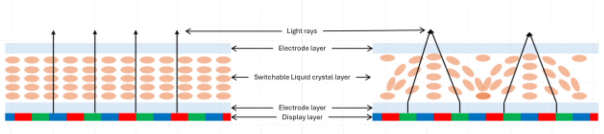

Figure 4. A simplified representation of the switchable lens is shown with and without an electrical field applied to the electrodes. When the electrical field is applied, the liquid crystal layer orientates itself creating the lens effect. Source: [4]

One important side effect of using a lens to create 3D is that the perceived resolution for the observer is lower than that of the full panel, as the resolution is split between the two eyes. The perceived resolution depends on factors such as the viewing position, the slant of the lens, and how the two images are woven. Generally, it will be slightly less than half the resolution of the original display panel.

3. Important performance metrics of (auto)stereoscopic displays

Crosstalk: refers to the leakage of light, where pixels intended for one eye (partially) become visible to the other [5]. This phenomenon can reduce perceived depth, degrade visual quality, and cause visual discomfort and ghosting [6]. Crosstalk is quantified as the ratio of undesired to desired light measured in luminance for each eye at a given position. To maintain high 3D quality, crosstalk levels should be kept below 2% [7].

Recently a novel automated and comprehensive characterization methodology was suggested [8] that evaluates crosstalk for multiple viewing positions. Moreover, it enables characterizing how crosstalk changes when users move away from the rendered viewpoint.

Such assessment of crosstalk provides further accuracy requirements for the eye-tracking system that is needed to mitigate increased crosstalk levels for the user and ensure high quality 3D.

(Optimal) Viewing zone: the zone in which crosstalk remains lower than 2% and the user achieves an acceptable 3D perception quality [8].

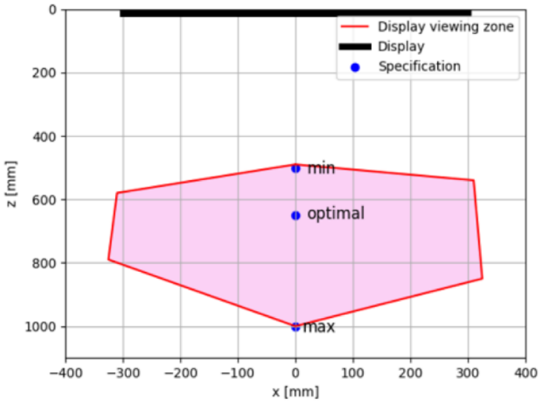

Figure 5. Example of a typical (horizontal) viewing zone of an autostereoscopic display

Perceived 3D resolution: the resolution of the image that is provided to each eye [9; 10]. If eg. a 4 MegaPixel panel is used to build a passive glasses 3D display, then each eye will only see (at best) a 2 MegaPixel images. Eg. If an 8 MegaPixel panel is used to build an autostereoscopic display with 4 viewing zones, then each eye will only see (at best) a 1 MegaPixel image (8 MegaPixel divided by 3 zones equals 2 MegaPixel, divided by 2 for a left/right image equals 1 MegaPixel).

3D Display brightness: brightness (in cd/m²) as perceived by each eye. It is important that the entire 3D display system is taken into account when measuring 3D display brightness. Eg. in the context of active glasses stereoscopic displays, the brightness measurement needs to take into account the fact that the shutter has a finite speed, and that therefore part of the light of the display light will be involuntarily blocked and not reach the eye [11].

Display calibration and stabilization: medical display systems require consistent image quality and characteristics (eg. defined transfer curve such as DICOM GSDF [12]) throughout the entire lifetime of the display. To achieve this medical displays typically have embedded sensors (photometers, colorimeters or spectrometers) that constantly measure, stabilize and standardize display behavior.

4. Use cases in healthcare

Stereoscopic displays are already being used in several healthcare applications today.

For example complex neuro- and retinal [13] surgeries are often performed with passive glasses based stereoscopic displays. And in robotic surgery the surgeon typically controls the robot by means of a console [14]. The console often contains an autostereoscopic display system.

But there are also less critical applications of (auto)stereoscopic displays in healthcare. Planning of complex surgical procedures [15] can be done by means of (auto)stereoscopic displays.

And more recently there are experiments with using autosteroscopic displays for patient communication [16], eg. to explain patients complex treatments or surgical procedures that need to be performed.

It is very important to understand that there is no “one fits all” solution that is fit for use for general use in healthcare applications. To start with, some of these use cases are single user (eg. a console in a surgical robot) while other ones are multiple viewer applications (eg. patient communication). For some of those applications the resolution is less important (eg. patient communication) while for others effective 3D resolution is crucial (eg. main 3D display for surgical procedures). Also, the viewing conditions of these use cases can be completely different. For example: the surgical planning use case is mostly a desktop application, while in case of the main 3D display for surgical procedures the display needs to offer good enough 3D quality for multiple people that are viewing the display from different positions in the operating room. And finally for some use cases the display is used to only look at 3D content, while for other use cases (eg. surgical planning) the display is mostly used as a regular 2D desktop display and only part of the time is showing 3D content. In this last situation the capability to fluently switch between 2D and 3D mode of operation is crucial.

5. Technology adoption and outlook

Adoption of (auto)stereoscopic displays in healthcare applications is gradually increasing but remains low. There are several reasons that can explain this.

It all starts with 3D content. Clinical workflows are strictly defined and adhered to. If there is no 3D content available and already being used in routine clinical practice, then a 3D display can add no value because there is simply no 3D content that can be shown on the display.

Moreover, changing clinical workflows and routines takes a very long time. This typically requires a strict process of evaluating the new routine in a controlled clinical trial to ensure that the new routine has a positive effect on safety and effectiveness and does not introduce any undesired effects to (subpopulations of) patients.

Healthcare is also a strongly regulated market [17]. Devices such as medical display systems that are used for diagnosis or treatment of patients need to pass a rigorous regulatory process before they can be put on the market. This ensures that only devices that are safe and effective will be used to diagnose and/or treat patients, but at the same time it can also slow down introduction of new innovative solutions. Especially when novel technologies (such as 3D displays) are introduced that could potentially raise new questions on safety or effectiveness [18] this typically requires additional measurements, tests or even clinical trials to be done. For example: in the case of using 3D displays one may raise the question whether the accommodation/vergence mismatch does not cause problems when using the display for longer periods of time.

Another challenge is related to proprietary solutions (eg. specific game engines [19] and interfaces towards 3D visualization devices. Currently, in many cases an application is developed for a specific game engine and XR device and has no cross-compatibility with other XR devices. This limits market adaption of XR solutions and slows down development of applications for new devices.

OpenXR [20] is gaining traction as an open standard developed by the Khronos group. Its goal is to solve the fragmentation of the XR application and device market. OpenXR provides a single cross-platform API that creates an abstraction layer between device and application. The 3D application can be built in a game engine or a native rendering stack and integrates the OpenXR API. This allows the application to be run on any XR device that supports OpenXR. Supported OpenXR devices have their own runtime which translates their capabilities (such as tracking, input devices, graphics devices, display buffers, etc) to the OpenXR layer. This approach is shown in Figure 6.

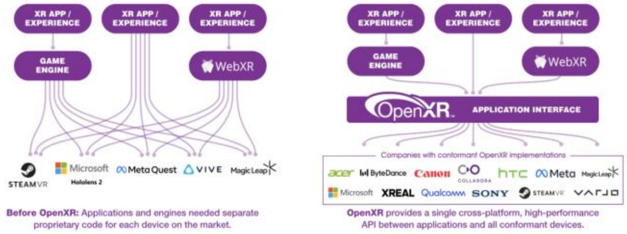

Figure 6. OpenXR middle layer (Source: https://www.khronos.org/OpenXR)

6. Conclusions

As autostereoscopic display technology continues to advance, its applications in healthcare are likely to expand, offering new possibilities for improving workflow efficiency and patient care.

Every healthcare application poses its own specific requirements related to number of viewers, viewing zones, ability to switch between 2D and 3D more, perceived 3D resolution etc.

Further adoption of (auto)stereoscopic display technology in healthcare is influenced by many factors including availability of 3D content in existing clinical workflows, regulatory pathways, and availability of standardized interfaces to rendering engines as well as XR devices.

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