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3D Displays

Trapped Particles Make 3D Images

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A technique employing photophoretic trapping has been applied to the implementation of a three-dimensional (3D) volumetric display system. This may ultimately enable the production of high-quality, free space images.

Volumetric displays allow 3D images to be depicted within a transparent physical volume. Since images occupy three physical dimensions, they exhibit the spatial characteristics that we associate with real world scenes (think of tropical fish in a tank). Images can be viewed glasses-free by multiple simultaneous observers and changes in vantage point allow content to be seen from different orientations. On page xxx, Smalley *et al*[1] describe basic research concerning a highly novel approach to volumetric display implementation which unlike the majority of techniques employed to date is in principle able to support the formation of 3D images in free space. This can enable user interaction via haptic probes – thereby allowing image content to take on the degree of 'solidity' that we would associate with the materials used in the creation of a physical version of the image (thus, for example, virtual clay could be moulded and would 'feel' like real clay).

For many years, volumetric systems have been the subject of extensive research and whilst it is relatively easy to make a small (table top) volumetric system that works fairly well, it is most difficult to develop larger displays that work very well. There are two overarching (but often conflicting) problems. The first relates to the selection of techniques that support the depiction of dynamic images of an appropriate visual quality, and the second concerns optical characteristics of the imaging volume (which must allow light emanating from the image to propagate, and emerge from it, without distortion).

In the case of the majority of volumetric systems prototyped to date, the imaging volume is formed by the rapid cyclic motion of a transparent surface (Figure 1) on which a sequence of image slices are depicted as it moves through the volume. Given the need to refresh images *at least* 30 times per second (so as to avoid perceptible flicker) the surface must move with rapidity. When the translational motion of a planar surface is employed, the image volume dimensions are invariably limited by mechanical issues arising from the mass and acceleration of the surface. In the case of rotational motion, instantaneous linear speed increases with distance from the axis of rotation and ultimately this impinges on image quality and so limits the imaging volume's diameter (there is also a 'dead' region in the vicinity of the rotational axis in which image points cannot be formed).[2] Furthermore, the motion of a surface through a volume precludes the insertion of haptic interaction tools.

Smalley *et al.* have sought to overcome these difficulties through the use of the photophoretic effect[3] by which laser light is used to trap and move small particles (with diameters ranging from 5 to 100μm). Thus, to create a point of light at a given location in 3D space, non-visible laser radiation is used to move a particle and as it passes through the required position, it is illuminated using either red, green or blue lasers. Given an appropriate parallelisation of this technique, complex, high fidelity, dynamic images could be formed.

There are at least three key advantages to this approach. Firstly, the cyclic motion of a surface is eliminated – movement being restricted to that of low mass particles. Secondly, the presence of these particles will have minimal impact on the propagation of light through the imaging volume, and thirdly, the image is effectively formed in free space: image components and interaction tools can coexist.

Smalley *et al.* provide interesting photographs of image content created using this technique – but these were captured using long exposure times. In implementing a viable system, there is therefore a pressing need to explore ways of increasing the speed of particle motion and of introducing parallelism such that multiple points of light (voxels – the 3D generalisation of a pixel) may be activated simultaneously. Here, a possible goal would be to support the simultaneous linear motion of a 2D array of particles which pass through the image volume so as to generate its third dimension.

As illustrated in Figure 2, the introduction of a high degree of parallelism in particle motion poses a further challenge relating to the illumination of image points (this is reminiscent of an equivalent problem encountered in the late 1960's by Adamson and Lewis in connection with a photochromic-based volumetric display[4]). In addition, the insertion of haptic interaction probes into the image volume is likely to give rise to shadow regions which interfere with the propagation of laser radiation used for particle motion and/or particle illumination. However, the judicious design of interaction tools will ameliorate this potential problem.

Despite more than 100 years of research into volumetric displays[5], relatively little work has been undertaken in exploring innovative ways of capitalising on key image characteristics. In terms of image resolution, it is unlikely that these systems will ever directly compete with high-end stereoscopic 3D display techniques in respect of photorealism. However, given their ability to provide natural support for motion parallax (vertical and horizontal) coupled with considerable freedom in viewing position, they offer exciting (and largely unexplored) opportunities – particularly in relation to the visualisation of complex forms of motion[6]. The approach adopted by Smalley *et al.* has the potential to provide the foundations for a new generation of volumetric display able to not only enhance our understanding of complex spatial and geometric dynamics, but also capable of supporting innovative interaction modalities.

Figure Captions

Figure 1:

Swept volume displays invariably employ the rapid cyclic motion of a surface. In (a) translational motion (for which images may only be updated once per cycle) and in (b) rotational motion of a planar surface (for which, in principle, images can be updated twice per cycle).

Figure 2:

Here we assume the formation of a 2D array of particles which are moved vertically upwards thereby forming the third dimension. In the simplest scenario the laser would not, for example, be able to illuminate particles A and C without also illuminating B. This type of problem is exacerbated as parallelism is increased.

References

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