On the Development of Higher Performance Volumetric Display Systems

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ABSTRACT

Volumetric display systems are able to depict images within a physical volume, thus automatically satisfying some major depth cues such as binocular and motion parallax. Within this article, we outline the operation of a swept volume volumetric display system prototype known as the Cathode Ray Sphere. This system is used to provide a basis for discussion upon the general limitations of volumetric technologies. We discuss possible architecture of display systems able, in principle, to operate at higher levels of performance and present some suggestions for the future development of volumetric display systems.

1 Introduction

Three-dimensional (3-D) display systems provide viewers with a sensation of depth by satisfying a certain subset of the visual depth cues [1]. For example, ray-tracing depicts the surface shading and occlusion properties of a displayed image for a defined viewing direction and virtual light source position [2]. Stereoscopic systems present to each eye a slightly different view of an image and therefore satisfy the binocular parallax depth cue. Autostereoscopic displays are able to provide stereoscopic images which change with a viewer's head position and therefore offer considerable freedom in viewing position.

A variety of display techniques are under investigation for the generation of autostereoscopic images. One approach concerns the generation of images within a transparent volume (image space). Since images depicted within this volume are able to occupy three physical dimensions a number of depth cues such as binocular and motion parallax are automatically satisfied without any need for the observer to wear special viewing apparatus. Display devices which operate in this manner are generally classified as volumetric display systems [3, 4].

There are two clearly distinguishable elements within any display system. Firstly, the physical display necessary for the visual presentation of the image scene and secondly the hardware (and perhaps software) responsible for the throughput and processing of the image data prior to its depiction. In the subsequent text we will distinguish between these elements by assigning to them the respective titles of *display unit* and *graphics engine*.

Volumetric displays have been the subject of continuous research activity for at least fifty years. During this period many volumetric display architectures have been proposed and a number have been developed to the prototype stage. Currently, various volumetric display unit technologies are under investigation [5-20]. This article outlines the operation of a volumetric display system known as the Cathode Ray Sphere (CRS) [5, 6] and uses this display as a basis for the definition of terminology and to highlight some of the difficulties which may be experienced in volumetric display system implementation. Reference is also made to two other volumetric display unit architectures which are used to illustrate aspects of display unit implementation. Having outlined the limitations of a display system such as the CRS, a number of general issues which concern the development of the next generation of high performance volumetric systems are discussed.

There are many ways in which a volumetric display system may be implemented. As a consequence, it is difficult to identify common characteristics which may be applied to all systems without exception. The issues discussed within this article apply to the majority of technologies which are either the subject of current investigation or have been proposed previously. They are not intended to apply to all systems *without exception*.

2 General Principles and Display Unit Classification

Essential to any volumetric display unit is a transparent display volume (image space). This provides a 3-D tableau. within which images may be depicted. In the case of the CRS, this volume is generated by the rapid rotation (20-25 Hz) of a phosphor-coated rectangular glass screen, the rotation axis of which lies in its plane and passes through its centre. As the screen rotates it sweeps out a cylindrical volume and, since the frequency of its rotation is chosen so as to be in excess of the eye's temporal fusion frequency [1], the screen cannot be directly discerned. Images are generated by addressing the image space with several electron beams, the gating and deflection of which are synchronised to the screen rotation. A prototype display unit employing two electron guns positioned 90^{o} apart

(compared with 120^{o} on earlier systems [5]) is illustrated in Figure 1. The blanking and deflection of each beam is synchronised to the motion of the screen through the use of an optical screen position sensor linked to the graphics engine. The use of more than one electron gun overcomes the inability of a single gun to write accurately to the screen through an entire revolution. When the screen's surface is at an acute angle to the optical axis of the electron gun, positional inaccuracies and elongation of the voxels generated on the surface of the screen become unacceptably large [7, 8]. Each electron gun is made responsible for addressing only one half of the image space. The production of images is achieved through the use of a dot graphics scanning technique (see Section 3.1) A vacuum of $\approx 1 \times 10^{-6}$ Torr is maintained within the display vessel, and screen rotation is achieved via magnetic coupling through the vessel wall [5].

From the above description, it may be seen that the CRS (and in fact any volumetric display unit) consists of three fundamental and interdependent mechanisms. These relate to image space creation, voxel generation and voxel activation. In the case of the CRS, for example, image space generation is achieved through the rapid rotation of a planar surface. Voxel generation is achieved by means of the phosphor coating deposited upon the rotating surface and voxel activation is affected by the use of electron beams which stimulate the emission of light from the phosphor material. In many publications, volumetric display systems are classified according to the nature of the image space generation technique and this has led to two general types of volumetric system; swept and static volume displays. Systems such as the CRS which rely upon the motion (either translational or rotational) of a surface are referred to by the former name and those which place no reliance upon mechanical motion, by the latter.

Whilst this classification of display systems is very convenient, it alone is insufficient as it distinguishes displays according to the nature of only one of the three underlying mechanisms and takes no account of the voxel generation and activation mechanisms (which are of equal importance in the characterisation of a display unit) [20].

In order to illustrate some of the concepts outlined in this article two other display units will be included in the discussion. The first of these, whilst not *necessarily* representing a feasible display technology, consists of a 3-D cubic array of light emitting elements. In this static volume architecture there exists a direct correspondence between each element and each possible voxel location within image space. The voxel activation mechanism takes the form of the electrical signal applied to each of the elements. This display unit will be referred to as the elementary display. The second display unit is similar to the CRS in that a rotating planar panel is used to sweep out an image space. However, rather than employ a phosphor coating this panel supports an array of light emitting elements. It will be assumed, unless otherwise stated, that each element within this array may be activated by the application of an electrical signal. During a single rotation of the panel (corresponding to an image refresh period) each element is able to give rise to multiple voxels. A display of this type was the subject of a patent granted to E.P.Berlin in 1979 [14, 26].

2.1 Some Image Space Characteristics

The characteristics of an image should not be affected by its location and orientation within image space. Consequently, the properties which may be attributed to a voxel such as shape, intensity, size and inter voxel spacing, should be invariant with respect to the location at which a voxel is activated. Therefore an entire image space should exhibit the properties of homogeneity and isotropy in regard to the positioning and generation of voxels. Possible voxel locations may then be described by a uniform co-ordinate system onto which the incoming image data may be mapped.

Of equal importance to matters concerning the placement of voxels are the optical characteristics of the image space, which impact upon the passage of light emitted from each voxel. For example, differences in optical characteristics (such as refractive index) within localised regions of image space or between the physical image space and the surroundings may result in image distortion. In such a situation, benefits which may be derived from an ability to accurately position voxels within image space may be reduced.

Should the refractive index of an image space medium be significantly greater than that of its surroundings (as, for example, is the case for static volume architectures employing a non-gaseous medium) then the apparent dimensions of the image space will differ from its physical size. For a rectangular shaped image space this would result in a diminution of image depth. In some applications this difference in refractive index may, when employed in conjunction with an appropriate image space shape, be used advantageously by providing image magnification.

In the case of swept volume display systems such as the CRS reliance is placed upon the cyclic motion of the voxel generation mechanism through the image space. This mechanism cannot exist in isolation, but must be bonded to a supporting structure (for example a glass plate). Any supporting structure will affect the propagation of light and cause voxels to appear to be moved away from their proper position. Furthermore it may cause a reduction in the observed voxel intensity. Whilst in the case of present volumetric display technologies, this effect may be of little consequence, it is likely to become a far more important consideration in the case of high definition (increased voxel density) large volume (requiring a stronger and therefore thicker supporting structure) systems. This matter is considered further in Section 5.1.

2.2 Voxel Capacity and Voxel Density

The total number of voxels which may be activated during each image refresh period is referred to as the voxel capacity (N) of the display unit and may be expressed as:

$$N = \frac{P}{Tf} \tag{1}$$

where T represents the time required to activate each voxel, f the image refresh frequency and P the concurrency supported by the voxel activation and generation mechanism(s). In the case of many volumetric technologies the voxel capacity plays an important role in defining the maximum achievable voxel density and this, in turn, impacts upon the level of detail which may be incorporated into image objects. Consequently, it is desirable to maximise the voxel capacity of any display unit.

For the majority of proposed volumetric technologies, the image update frequency is equal to, or greater than, the minimum flicker fusion frequency. For a display such as the CRS, a typical value[1] for T would be 400ns and therefore with an image refresh period of 40ms and a display unit exhibiting a concurrency of unity (corresponding to the sequential generation of voxels) the voxel capacity would equal 100,000. In the case of swept volume and some static volume technologies, this total number of voxels must be distributed around the image space and cannot be compressed into one or more localised regions. As a consequence a display technology such as the CRS with a voxel capacity of 100,000 would typically depict images containing fewer than 20,000 voxels.

Reductions in the magnitude of T and also in f (at the cost of increase image flicker) will only result in a marginal increase in the voxel capacity. Significant increases in N may be achieved by increasing the concurrency of the display unit. For the CRS (or any other beam addressed display) this would require an increase in the number of independently deflected beams.

Returning to the two other display units referred to in Section 2.1. In the case of the elementary display, each light emitting element could in principle be addressed uniquely by the graphics engine (maximum concurrency). Alternatively a row and column addressing technique could be employed so as to reduce the number of interconnections and thereby reduce the concurrency. In the case of the display unit employing a rotating panel of discrete light emitting devices, the concurrency is determined by the number of elements and by the nature of any row and column addressing technique employed for the passage of information to them.

3 The Impact of the Display Unit upon the Graphics Engine

The precise techniques employed in the implementation of a display unit have a major, and often subtle, impact upon design and operation of the graphics engine. Whilst it is clearly important to consider the detailed interaction between the two, it is instructive to consider the following general issues which apply to all, volumetric displays:

1) The degree to which the display unit supports parallelism in the voxel activation process. This impacts upon the number of data paths which are to be incorporated within the graphics engine.
2) The peak data transfer rate which may be required by the display unit as a consequence of its voxel capacity and/or maximum voxel density characteristics. This determines the maximum throughput of information which must be accommodated by the graphics engine.
3) The extent to which the data must be processed and ordered [9] prior to its passage to the display unit. This is of particular consequence in the case of swept volume and beam addressed static volume systems.

These, and other, issues are illustrated in the following sub-sections by considering the implementation of a graphics engine employed in conjunction with a CRS prototype.

3.1 The Implementation of the CRS

The cylindrical image space, generated by the rotation of the phosphor coated screen, is divided into a number of sectors, and as the screen passes through each of these, those voxels which are to be drawn within that portion of the image space are output to the display unit. This provides a simple and effective method of ordering the data although, as a consequence, each voxel drawn within the image space is subject to a positioning uncertainty the magnitude of which is a function of the distance of the voxel from the rotation axis. The controlling computer is responsible for the

[1] Without electron beam Post Deflection Acceleration.

determination of the best sector within which to place each voxel and takes into account the non-zero screen thickness and any non-axial misalignments of the screen. Voxels are generated sequentially (P=1) and, due to the difficulty of raster-scanning a volume to the same resolution as a conventional 2D monitor (due to the rapid beam scanning speeds required) [5], a dot-graphics scanning technique is employed [9]. The number of sectors used is determined by the radius of the screen. The control system permits the use of 256, 512 or 1024 sectors, although 1024 sectors are generally employed with screen dimensions of 16cm x 16cm, leading to an angular range of $\approx 0.35^{\circ}$ per sector.

The time T required to plot each voxel is the sum of the time needed to move the electron beam to the required voxel location (the move time, T_m) and that for which the beam must excite the phosphor so as to create a voxel of sufficient intensity (the dwell time, T_v). The move time is ultimately limited by the slew rate of the deflection amplifiers, and the dwell time by the characteristics of the phosphor employed in combination with both the accelerating voltage applied to the electron beam and the beam current. The dwell time also includes the rise and fall times of the beam blanking apparatus. The maximum number of voxels (N_{sector}) that can be depicted in each sector may be expressed as:

$$N_{sector} = \frac{N}{S} = \frac{P}{SfT} \tag{2}$$

where S represents the number of sectors. For example, with a voxel capacity of 100,000, S = 1024 and P=1, the maximum number of voxels per sector ≈ 97. Should attempts be made to exceed this sector capacity, image data may be lost. In order to reduce the impact of this limitation, should a sector become filled, the processing software will attempt to place the voxels in the adjacent sectors. These may in turn may become overpopulated and this can lead to a further re-distribution. In the case of this CRS prototype, with 1024 sectors and a relatively small image space, this voxel redistribution generally has had no discernible effect upon the quality of images depicted to date.

Images containing two colours are made possible by coating each face of the screen with a phosphor which emits light of a different peak wavelength under excitation by the electron beam. The phosphor coatings must however be sufficiently thin so as to retain the transparency of the screen. It is also important for the phosphor to be strongly bound to the rotating target screen and to have a very short luminescence decay time in order to prevent image blurring due to the screen moving an appreciable distance during the visible portion of the decay time.

The use of two electron guns allows the entire image space to be addressed. However, in order to ensure the absence of image discontinuities, the proper alignment of the guns with respect to each other is vital. This alignment is especially critical within those regions where one electron gun takes over the task of addressing the screen from the other. Rather than placing total reliance upon a high degree of mechanical alignment of the electron guns, the control software provides a method of visually ascertaining and compensating for misalignments, and some development work has been undertaken upon automatic alignment mechanisms. This operates through the use of transparent conductors placed upon the surface of the rotating screen. Under computer control, the system is calibrated by moving the electron beam(s) to different locations upon the surface of the screen, and by means of the conductors the control system is able to monitor both the beam location and beam current.[2] In the case of beam addressed display systems, the concurrency supported by the display unit may be increased by the use of additional beam sources. This offers to increase the voxel capacity and so permit a greater voxel density. However, as the voxel density is increased, it is important to improve the voxel placement accuracy. Consequently the alignment between beam sources must be achieved with even greater precision.

3.2 The Control System

The general architecture of a prototype control system developed for use in conjunction with the CRS is illustrated in a simplified manner in Figure 2. This system was based on a 486 personal computer (PC) equipped with a custom built control card. The main responsibility of this card is to ensure correct synchronisation between the screen position and the output of data (voxel descriptors). The two memory banks illustrated in Figure 2 are arranged so as to permit the contents of one to be updated by the computer whilst the other is output to the display (double buffering) and so enable image animation. Voxel descriptors are passed to the card via the PC's ISA bus.

Each voxel descriptor is calculated by the PC and is held as a 32 bit value providing horizontal and vertical deflection co-ordinates values (12 and 10 bits respectively), intensity (8 bits) and the gun selection (2 bits). The control card enables each image frame output to the CRS to contain, in principle, up to 256,000 voxels. The higher precision used for the horizontal deflection value reflects the need to ensure that, as the angle between the screen and electron gun varies, voxel positioning continues to be sufficiently accurate. The computer also determines the sector within which each voxel is to be placed.

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[2] In systems such as the CRS, the automated control of beam current is most important and ensures that each electron gun gives rise to voxels of similar intensity (i.e. grey scale calibration).

Once output from the control card the voxel descriptors are converted into analogue form using Digital-to-Analogue Converters (DACs), before being passed to high voltage amplifiers which directly drive the electrostatic deflection plates and control grid of each electron gun. The deflection plates of each gun are driven by separate amplifiers which are active irrespective of which gun is enabled. The DC coupled amplifiers used for this CRS prototype provided a differential output voltage of approximately 800 V and operated up to 4 MHz.

4 The Mapping of Image data into a Display Unit: Subspace

The concurrency supported by a display unit does not necessarily correspond to the number of voxel activation sources. For example, in the case of the CRS configuration described above, although there are two electron beams only one is operational at any time. As a consequence, in this form the display does not support concurrent voxel activation.

It is convenient to consider the physical region addressed by each voxel activation sub-system as a sub-space of the image space. An image space therefore consists of a number of subspaces and each voxel activation mechanism is responsible for the production of voxels within one of these regions. Subspaces may overlap in both the spatial and temporal domains. For example, in the case of the two gun CRS display, each electron gun may write to only one half of the image space and the two are not allowed to address the image space simultaneously. The subspaces are therefore separated both spatially and temporally. Should the dead zone criteria be relaxed it is possible to permit each electron gun to address perhaps two thirds of the image space volume. This would then indicate partial overlap between the two subspaces. As a consequence the region of image space within which the subspaces overlap could exhibit an increased voxel capacity resulting in an undesirable loss of overall image space homogeneity.

Should there exist η voxel activation sources able to address a total of N voxels during each image refresh period then by definition, there are η subspaces. Assuming that each subspace contains the same number of voxels the throughput of voxels into the image space may be represented by:

$$\eta\left(1 \to \frac{N}{\eta}\right) \tag{3}$$

where the number of voxels in each subspace (N_{sub}) corresponds to N/η. In the case of the elementary display unit model introduced in Section 2 in which each light emitting element has a unique electrical connection (maximum concurrency), the region of image space occupied by each element corresponds to a subspace. The number of activation sources η is therefore equal to the voxel capacity, and so may be represented as:

$$N(1 \to 1)\,. \tag{4}$$

That is, there are N pathways into the image space and each is responsible for updating one voxel. The concurrency of this display unit model may be reduced through the incorporation of a row and column addressing technique. For example, if the elements are interconnected so that the number of connections (data paths) into the image space is equal to $2N^{2/3}$ (which corresponds to the number of subspaces), then the mapping of information into the image space may be represented by:

$$2N^{2/3}\left(1 \to \frac{N}{2N^{2/3}}\right) \tag{5}$$

indicating that each connection is responsible for the activation of $N^{1/3}/2$ voxels.

In general, the number of voxels within each of the subspace may not be identical. Consider therefore a system in which there are η subspaces and the number of voxels contained within the j^{th} subspace is n_j. Then the mapping of information into the image space may be represented by:

$$\sum_{j=1}^{\eta}\left(1 \to n_j\right)\,. \tag{6}$$

For example, consider the display unit employing a rotating planar array of discrete light emitting elements referred to in Section 2. It is assumed that the display employs $N^{2/3}$ equally spaced elements arranged in square which are distributed upon both sides of the axis of rotation. Furthermore, for simplicity, each element is assumed to have a unique electrical connection to the graphics engine. The number of elements is therefore equal to the number of subspaces. The number of potential voxels which may be generated by each element will be dependent upon the radial distance of the element from the axis of rotation (ensuring approximately equal voxel spacing along each subspace). All elements at an equal radius should therefore be capable of generating an equal number of voxel and so may be grouped into columns which lie parallel to the axis of rotation. Each column of subspaces may be denoted by the integer j and if, in the first instance, only elements on one side of the rotational axis are considered, it is apparent that $0<j\leq 0.5N^{1/3}$.

Denoting the adjacent element separation within the array by ξ, and separation of voxels along the length of each subspace by β, it follows that the number of voxels activated (n_j) within a subspace lying at a radius r from the axis of rotation is approximately $2\pi r/\beta$. However since $r=j\xi$:

$$n_j \approx \frac{2\pi . j\xi}{\beta} \tag{7}$$

and the mapping of information into the image space may be represented by:

$$N^{1/3} \sum_{j=1}^{0.5N^{1/3}} \left(1 \xrightarrow{\approx} \frac{2\pi . j\xi}{\beta} \right). \tag{8}$$

The inclusion of symmetrically placed voxel generation elements on either side of the axis of rotation results in pairs of spatially coincident subspaces and can be used to provide a method for the generation of two colour images.

The determination of the value of ξ/β is of interest. Considering the situation in which there is to be approximately equal voxel spacing both radially and along the length of each subspace i.e. $\xi/\beta=1$, the above mapping may be rewritten (in approximate form) as:

$$N^{1/3} \sum_{j=1}^{0.5N^{1/3}} \left(1 \xrightarrow{\approx} 6j \right). \tag{9}$$

This indicates that the innermost column of subspaces will each be responsible for the generation of ≈ 6 voxels, the second column for ≈ 12, the third for ≈ 18 etc. For example, an array containing 100 by 100 elements wholly located on one side of the axis of rotation would have the potential voxel capacity of more than 3 million.

Image space is comprised of one or more subspaces. These subspaces may spatially overlap or may be physically separated. According to the definition of subspace used in this article, voxels may only be placed within subspace regions and so it follows that image space may, in some cases, be discontinuous. Those portions of image space within which subspace does not exist are referred to as *dead image space*.

Consider an image space which is composed of n subspaces each of volume V_j, and in which there exists dead image space having a total volume V_d. The effective image space volume V_e may be expressed as:

$$V_e = \sum_{j=1}^{n} V_j + V_d \,. \tag{10}$$

The effective image space volume may be considerably greater than the actual physical volume. For example, in the case of a swept volume display unit employing the reciprocating motion of a planar surface, the effective image space is approximately twice the physical volume, whereas in the case of the two gun CRS in which each electron gun addresses one half of the image space, the physical volume and effective volume are equal.

5 High Definition Systems

A high performance volumetric display system may be characterised by an homogeneous and isotropic image space which permits the depiction of full colour images and in which the voxel capacity and achievable voxel density (when considered in combination with voxel size) are sufficient for the purpose for which the display system is intended. The development of display unit architectures capable of supporting the generation of high quality images and furthermore permitting the isotropic and rectilinear transmission of light from each voxel location is a most challenging research exercise.

All volumetric technologies known to the author (and which are the subject of current research activity) permit the generation of translucent voxels. Volumetric displays appear to be most suited to the depiction of the spatial separation, dynamics and 3-D form of data sets. Spatial separation may be most clearly observed when large portions of an image space are void. In such circumstances the translucent nature of voxels is not an apparent disadvantage as the three dimensional nature of images depicted within image space would appear to compensate for the lack of image opacity. Whilst it is possible that future display technologies will incorporate voxel generation mechanisms able to give rise to opaque voxels this does not appear to be a *primary* requirement at the present time.

The introduction of concurrency within the voxel activation process necessitates the replication of hardware at the output stages of the graphics pipeline. Of particular consideration is the technique employed to pass grey scale information to the voxel activation mechanism. Since at some point this information must be converted from digital into analogue form, the number of DAC's which must be supported within the graphics pipeline will, in general, correspond to the concurrency supported by the display unit. Further additional DAC's may be required in the case of beam addressed displays in order to direct each beam to the required location within the display volume .Ultimately, unless alternative solutions are identified, this will limit the parallelism which may be economically supported within the graphics pipeline.

Static volume display units have considerable potential. For some time, however, the primary area of activity in this area is likely to focus upon the identification of materials which have the appropriate spectroscopic properties, or alternatively, in the case of systems employing static 3-D element arrays, upon the development of automated assembly techniques. The discussion within the remainder of this section is therefore limited to swept volume systems.

5.1 Swept Volume Beam Addressed Displays

For display units of this type, increases in the voxel capacity permit increases in both voxel density and in the number of voxels which may be accommodated within each sector. Concurrency in voxel generation and activation processes provides the most effective method by which a high voxel capacity may be achieved. However, the use of multiple beams requires a high degree of alignment between the beam sources. Furthermore, as the maximum attainable voxel density is increased, there must be a corresponding increase in the voxel placement accuracy. This imposes more stringent demands upon the beam alignment and deflection apparatus. In the case of a system such as the CRS, any increase in the required voxel placement accuracy will make it necessary to reduce the extent of the region of image space addressed by each beam source. As a consequence, whilst the addition of beam sources will increase the number of temporally overlapping subspaces, both the spatial and temporal extent of each subspace will be reduced. For example, in the case of high performance systems, although doubling the number of beam sources will in principle double the voxel capacity of the display, the required increase in voxel placement accuracy will necessitate a reduction in this value.

For swept volume displays employing rotational motion the transmission of light through the image space is effected only by the presence of the rotating surface and possible centre shaft. The thickness and optical properties of this structure result in a visual dead zone which occurs when the surface of the structure lies at an acute angle to the observer. This dead zone takes the form of a narrow region within which voxels appear to have a diminished intensity, and is caused by both refraction within the structure and (for example, in the case of the CRS) the physical characteristics of the phosphor coating. Other visual problems are caused by the presence of any centre shaft which may be needed to provide mechanical stability. However, for example, in the case of a planar surface which is able to operate without a centre shaft, the finite thickness of the rotating structure causes a core region of the image space to be occupied at all times. Light which passes through this core region is attenuated and this compounds upon the impact of the visual dead zone.

Swept volume displays which employ translational motion of a surface offer to provide a more homogeneous and isotropic image space with superior optical transmission properties. However, these advantages may be offset by the more complex mechanisms required to effect the motion of the surface and by a restricted viewing angle.

The visual dead zone problem referred to above is likely to present the greatest problem in the development of high performance swept volume display units with large image space dimensions. It is unfortunate that the voxel generation mechanism is unable to exist without the presence of a structure able to provide physical support. The thickness of this structure determines the extent of the visual dead zone and both increases in image space dimensions and voxel placement accuracy will require structures able to provide greater physical support. Should this

increased support be obtained by increases in the thickness of the structure, or by the inclusion of a centre shaft, the visual dead zone will increase in severity.

5.2 Swept Volume Systems Employing a 2-D Element Array

Display Units of this type offer high concurrency within the voxel activation and generation processes and since multiple beam sources are not required, the complexities of beam registration are eliminated. Clearly, image quality is greatly affected by the characteristics of the light emitting elements and the nature of the surface upon which they are supported. A display unit employing a planar array of elements moving with translational motion offers, in principle, to provide an architecture capable of high concurrency and which is free across a restricted range of viewing positions from any visual dead zone. Unfortunately the mechanical difficulties of implementing the translational motion at frequencies in excess of 25Hz reduce the feasibility of such a system.

6 Discussion

Volumetric display systems have been the subject of research for many years. A large number of the systems proposed and constructed in prototype form during this period have employed existing and well understood technologies and so it may perhaps be considered surprising that these displays have not advanced beyond the experimental phase. There may be many contributory factors which have affected the development of these systems. However, it is apparent that whilst it is a relatively minor (although time consuming) undertaking to produce an operational display capable of depicting basic images, the development of systems able to portray high quality images which may be viewed from practically any orientation without degradation of the image quality is a most difficult, challenging and complex task.

It is possible to identify a number of characteristics which are desirable in any volumetric display system. However, their relative importance often varies with the type of application for which the display system is intended. Future generations of volumetric display system will offer a high voxel capacity and this may only be achieved by the inclusion of parallelism in the voxel generation and voxel activation sub-systems. Studies undertaken by the author indicate that swept volume systems employing 2-D element arrays may provide the basis for the *first* generation of high performance volumetric systems.

There are a large number of techniques which may be applied to the implementation of the three sub-systems within a volumetric display unit. Whilst this provides many opportunities for future development it also leads to uncertainty in identifying the best course to follow. This was highlighted during a discussion at a meeting of the Radio Section of the IEE on the 24 March *1948*, which related to a publication [21] detailing the application of volumetric display systems to aircraft radar visualisation. During the discussion Dr R.A.Smith made the following comment:

> *"The paper gave me the impression that we are suffering from an embarras de richesse; anyone coming into this field finds so many possible displays that he may be in doubt about which line to investigate. ..."*

In their reply to various issues raised by the audience, the authors of this highly interesting article made the following comment:

> *"...A number of speakers have commented that these displays tend to favour qualitative rather than quantitative use. Most three-dimensional observation in actual life tends to be qualitative. When it becomes quantitative, it usually reduces to a coincidence of two points, as in catching a ball or touching an object, which is analogous to our use of electronic markers in the displays. It is difficult to treat the problem theoretically, and detailed comparisons between different displays for different applications must await actual experience. We have no doubts about the fundamental possibility of usefully presenting three dimensions, but we are still sounding the problem before setting the course."*

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