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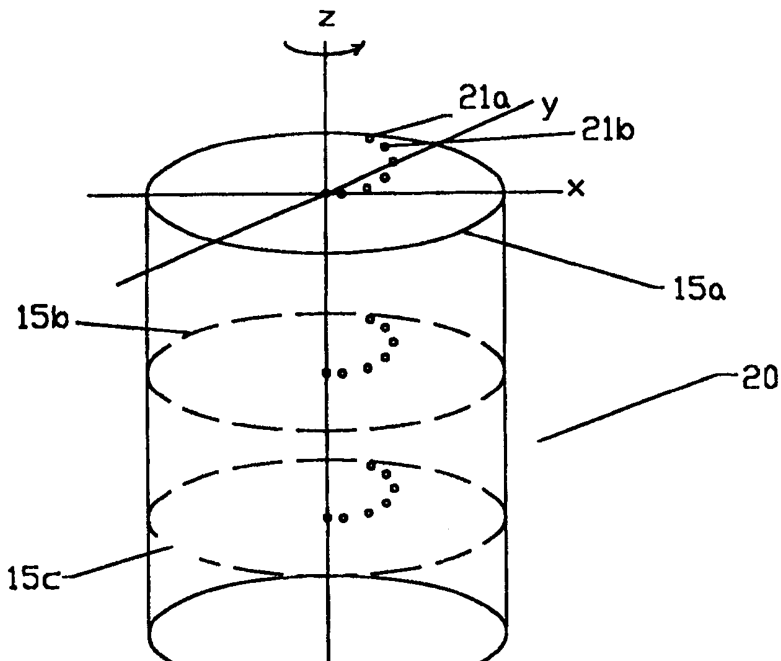
**(54) Title:** A HIGH DEFINITION VOLUMETRIC DISPLAY SYSTEM

**(57) Abstract**

A three–dimensional display system is described. An arrangement of optical emitters within the display is arranged so that they provide an isotropically distributed array of light emitting sources within the display volume. The display incorporates a solid optically transparent support structure which contains the optical sources and is rotated to provide an appropriately shaped display volume. The optical sources may be illuminated within the display volume in such a manner that a three–dimensional image is generated inside the display volume. In one embodiment, the optical sources are laid out on planes perpendicular to the axis of rotation of a support structure whereby for any single plane, the optical sources are located relative to one another on corresponding tracks so that the optical sources form a spiral when viewed along the axis of rotation. The planes may be arranged on top of one another and sequentially displaced around the axis of rotation so that the optical sources lie on the surface of a helix. The optical sources may be light emitting diodes or similar optoelectronic devices. The optical sources may be driven by means of parallel data which is multiplexed where the degree of serial/parallel mixing is controllable and dependent upon matching the display to the control electronics. Suitable applications include medical and similar imaging, traffic control and other applications where a three–dimensional representation of a particular image may be required.



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# A High Definition Volumetric Display System

**(Courcelle)**

## Field of the Invention

The present invention relates to three-dimensional display systems. More particularly, although not exclusively, the present invention relates to volumetric three-dimensional display devices suitable for use in applications which include medical imaging, computer aided design and molecular modelling. Such uses require high definition, high quality three-dimensional images are as well as image quality which is substantially invariant with viewing direction.

The methods an apparatus discussed herein permits large numbers of voxels to be illuminated during each image refresh period. This enables image objects and scenes to be depicted at high resolutions and therefore represents a considerable advance over existing volumetric display systems. Further, the system described herein minimises variations of image quality with viewing direction.

## Background to the Invention

The present invention relates to volumetric three-dimensional image generation. In such systems, image objects and scenes are depicted within a physical three-dimensional volume (display space).

At the present time, there are a relatively large number of ways in which volumetric three-dimensional display devices may be implemented. A fundamental difference in the various implementations resides in the method by which the physical volume (display space) is generated. Some systems use the rotational motion of a planar, helical or other surface geometry. Other systems use a reciprocating planar surface. Further, static systems exist (or have been proposed) in which no motion is required to generate the display space. Examples of this latter type correspond to a display space comprising a volume of solid or gaseous material, or alternatively a three-dimensional matrix of optoelectronic devices where each of the optoelectronic devices is capable of generating an image voxel within the display space.

Images may be generated (i.e. voxels illuminated) in various ways. A number of systems use a beam scanning approach (beam scanned devices) using laser or electron beams. In systems which use motion for display space generation, a suitably scanned and modulated laser beam illuminates voxels at the points at which the beam is made to intersect with a semi-opaque surface. Similarly an electron beam, at its point of intersection with a phosphor coated surface, will stimulate an optical emission and can be used to generate a voxel. In the case of a completely static solid or gaseous system, voxels may be generated by a two step excitation process at the point of intersection of two invisible beams. Other systems use optoelectronic devices for voxel generation. Such a system may be embodied as a two dimensional planar matrix of optoelectronic devices located upon a rigid surface which sweeps out the display space. Alternatively, the optoelectronic array may be a three dimensional matrix in the case of a static system which employs no mechanical motion. Various other techniques also exist, however these tend to be variations on the above.

All of the above types of displays generally implement or adapt known technology and, in applications requiring high image resolution, can exhibit inherent display limitations which will be discussed in detail below.

Generally volumetric display technologies permit images to be viewed through a wide, and sometimes practically unrestricted, range of viewing angles. However, many of the existing display implementations produce images having a perceived quality which is not invariant with viewing position. That is - images are faithfully reproduced only when viewed from certain locations. This therefore restricts the viewing angle.

It is considered that the present invention represents a significant departure from both conventional scanned beam devices (for example see International Application Nos. PCT/NZ93/00083 and PCT/NZ96/00028) and matrix devices (for example see US patent No. 4,160,973).

Systems, in which the image space is generated by the rotational motion of a surface such as those described in the abovementioned documents suffer from a several intrinsic problems. Whilst these may not be a significant disadvantage in a number of applications, their impact increases with the demand for greater image quality, clarity and definition. Such problems ultimately limit the system performance and may set an upper limit to the size of the display space.

One problem is caused by refraction within the body of the rotating surface. For example, in a beam addressed system, a surface layer (such as a phosphor coating) interacts with the beam(s) thus generating visible voxels. This layer must be fabricated on a rigid body. Similarly, in a matrix system employing rotational motion, the optoelectronic components must be bonded to a rigid body. The rigid body should be transparent and will have finite thickness. Such characteristics will produce refraction effects when the body is viewed at an oblique angle whereby light emitted from the layer or matrix passes through the transparent material from which the rigid body is formed. In some cases, total internal reflection in the rigid body will cause voxels to be distorted and/or attenuated. The effect of these aberrations is that when the rigid body is viewed edge on (or at angles close to this position), optical distortions may be visible resulting from the presence of the rigid body and/or occlusion caused by the devices/material which generate the voxels.

For example, in the case of a system using a planar rigid body, the rigid body, produces images which, when viewed in line with the axis of rotation, are distorted by a region or band of strong attenuation.

Flexing of the rigid body may often exacerbate the abovementioned problem. The rigid body must therefore be capable of resisting any flexing produced by its motion. Also, as the size of the display space is increased, it may be necessary to increase the thickness of the rigid body in order to avoid flexing. However, as the thickness is increased, the optical distortions described above become more severe.

A further problem arises along the axis of rotation. In order to permit the rigid body to be as thin as possible (while at the same time ensuring mechanical stability) it is often necessary to provide additional support in the form of a centre shaft. A rigid body having a helical geometry provides greater mechanical strength than a planar configuration. However, in both cases, in order to view images in line with, and on the opposite side of, the axis of rotation to the position of the observer, it is necessary to look through the rotational axis and hence view light which has passed through both the rigid body and centre shaft (if present). Again this leads to optical distortions in the image. Even in the case of systems which employ a planar rigid body and no physical centre shaft, the rigid body generates an artificial centre shaft with a diameter equal to the thickness of the rigid body.

Matrix systems employing rotational motion can have even greater associated problems whereby the optoelectronic devices add to the thickness of the rigid body and may occlude light emitted from other elements located at a greater depth within the display space. Further, the high density of electrical connections needed to activate each device can contribute to distortion or occlusion of images.

Scanned beam devices activate voxels sequentially or by the inclusion of more beams. Such scanning systems are able to demonstrate a degree of parallelism (the degree of parallelism being no greater and often less than the total number of beam scanning devices). Since the generation of each image voxel occupies a finite time, for each beam scanning system there is an upper limit on the number of voxels it is able to generate during each image refresh. Generally this equals the period of motion of the rigid body. It is not possible to reduce the period of motion of the rigid body below that required in order to produce substantially flicker-free images. Therefore, it is not possible to extend the time available for each image refresh beyond that required for tolerable image flicker. Thus, the only way of increasing the number of voxels illuminated during each refresh period (and therefore generate images containing more detail) is by using more beams and beam scanning devices.

When multiple beams and beam scanning devices are employed, registration between the beams becomes a major issue. Reliance may therefore have to be placed upon highly accurate mechanical alignment of the beam sources, beam scanning devices and driving electronics. The alignment accuracy required increases as the maximum attainable voxel density is increased. In systems using charged beams, the beam(s) may not propagate in a rectilinear manner. Electronic alignment methods may therefore be required such as those mentioned in International Application No. PCT/NZ93/00083. In the case of systems using laser beams, electronic alignment techniques are unlikely to be easily implemented.

In summary, in order to increase image detail (by enabling larger numbers of voxels to be illuminated at a higher density), it is necessary to increase the degree of parallelism in voxel activation. In the case of scanned beam devices, this necessitates the provision of multiple beams and beam scanners able to position voxels with great accuracy. As the voxel density is increased the required placement accuracy is greater and so therefore is the degree to which the beam scanning devices must be mechanically and electrically aligned.

The result is complex calibration procedures throughout the operational life of the display system. In certain cases electronic alignment techniques may be used, however this may cause further complication and additional computational overheads.

While the techniques proposed in the abovementioned International Applications overcome some of these difficulties, aberrations and calibration difficulties nevertheless become significant when the need for higher image definition arises.

Considering systems which do not use motion for display space generation, and consist of a static three-dimensional matrix of optoelectronic (or other) elements. Each member of the matrix is able to give rise to a single voxel. Consider a cube containing an array of optical devices (eg: LEDs) spaced regularly throughout. The sources are activated in turn or simultaneously to produce the desired image. The optical sources are stationary and can therefore illuminate only a single location in space. The disadvantage of such a device is that a large number of sources are required. For example, if the cube has sides of length 20cm, and intervoxel spacing of 0.1 mm, then 8 million optical sources would be needed. This leads to a corresponding large number of connections resulting in associated obstruction aberrations.

The number of connections and optical sources can be greatly reduced by display space generation through the motion of a rigid body. It should also be noted that the number of external connections may be reduced by multiplexing. For example, an array of n by n optical elements may be addressed by 2n + 1 connections. Elements within this array are addressed sequentially. By grouping elements, it is possible to adjust the degree to which elements within the display space are addressed in both serial and parallel form. However, multiplexing does not reduce the number of connections which must be made to the elements as a whole. Each must be directly addressed and, given the large number of elements required, it is necessary to have a large number of connections within the display space. This can lead to image occlusion and distortion. It is noted that the connections to each optical element may take a non electrical form.

Further potential problems may be found with a 3-D array implementation if constructed in a known arrangement of the optical devices and connections. At certain viewing angles, the optical devices and related components will align. Thus, an obstruction aberration may be visible as image striation. This may be present in more than one viewing direction, depending on the geometrical layout of the obscuring components.

Examples of a matrix display employing rotational motion include that described in US Patent No. 4,160,973 (Berlin). The Berlin device uses a 2-D matrix of LEDs which are rotated through a volume creating a display space which is in the shape of right cylinder. While reducing the number of optical sources and corresponding connecting wires, this construction does not provide the desired optical homogeneity and isotropy. The presence of the rigid body upon which the LEDs are mounted may interfere with the image. Such aberrations result not only from the rigid body itself, but also from the regular layout of the LED's on the planar array. For any viewing direction, there will always be a situation (in any complete revolution) where all of the LEDs lie in a plane parallel to a line joining the viewer's eyes with the centre of the display device. Further, on the rigid body there will exist a large number of connectors. The layout of the connectors may follow a regular pattern. When the LEDs, the array and related components align, an obscuration aberration may be visible in the form of image striation. Refraction and possible total internal reflection effects will cause further image distortions (as described above in the case of systems using rotational motion). These distortions are implicit in systems using the rotational motion of a rigid body and result directly from the difference between the refractive index of the rigid body and they of the empty display space which it sweeps out.

Also, the presence of a central mounting shaft will interfere with optical emission. Although this may not be a significant disadvantage in many applications, it would be desirable to have a completely optically homogenous isotropic image space which includes a uniform central core.

A further limitation of known volumetric displays relates to the way in which the data is written into the display space. Consider a control and graphics processing system which is responsible for taking voxel data from a host computer and passing it in the appropriate form and at the appropriate time to the display. The operator should, in the ideal case, be able to treat the display space as a 3-D a cartesian space (using whichever form of coordinate system is appropriate). That is - the display space should be able to represent data points (voxels) on a regular grid-like spacing. Thus, there should be a direct mapping of coordinate values into image space voxels. The display space should therefore exhibit the properties of homogeneity and isotropy; image characteristics being invariant with image position within display space. Consequently, the perceived image quality should be invariant with viewing direction.

It is possible that these conditions may never be fully realised. However, the present invention provides a solution which is expected to maximise these display space metrics. A further benefit offered by the present invention is an increase in the number of voxels which may be illuminated within each image refresh. This is best described by examining the limitations to various current systems.

Voxel data originating from the host computer and suitably processed by the graphics processing system passes to the display space hardware via a number of data pathways. It can therefore be considered that the data pathways act as the interface between the graphics processing hardware and the display space hardware voxels. Considering for example, a beam scanned system employing rotational motion. In such a configuration, each beam deflection system is responsible for sequential voxel activation. Several beams may be required in order to allow voxels to be generated throughout the display space (see International Application No. PCT/NZ93/00083 for example). The degree of parallelism exhibited by such a display is therefore no greater than (and perhaps less than) the number of beam deflection mechanisms. Increasing the number of beam deflection mechanisms will increase the degree of parallelism. However, the degree of parallelism is inherently limited in such devices. As noted above, increasing the number of beams/beam scanning mechanisms leads to calibration and registration problems.

In systems employing a 3-D matrix of static elements, the degree of parallelism may be reduced by multiplexing the optical elements. The number of elements remains high and so does the extent of the interconnection between the multiplexing hardware and the 3-D array of elements.

In the case of a matrix display employing rotational motion, such as that described in US Patent No. 4,160,973 (Berlin), the problems in data transmission reside in writing sufficient data to the rotational planar LED array per image refresh period. The Berlin device permits parallel data transfer from the rotating display electronics to the LED array. However, the rotating display electronics memory is updated via a serial optical link. Therefore, it would appear that an inherent upper limit to the rate of data transfer will limit the number of voxels which may be modified during each image refresh period. The Berlin system allows for incremental updating of the image (i.e. a percentage of the total number of available voxels). However, it is likely that high definition images involving gross movement and covering large areas of the image generation volume would exceed the data transfer capabilities of such a data transfer link. That is - while the graphics processing system may exhibit any required degree of parallelism, and while the 2-D optoelectronic array will be configured to exhibit parallelism, the data transfer link is inherently serial and will ultimately limit the throughput of information into the display system.

A further effect associated with a technology employing the rotational motion of a 2-D optoelectronic matrix such as that described in the previous paragraph resides in the varying workload of the optoelectronic components. The length of the path (track) swept out by each of the optoelectronic devices is proportional to their radial distance from the axis of rotation. Given that each of these devices is responsible for voxel generation along the circumference of a circle at intervals (tracks) which are constant throughout the display space, it follows that the workload of each device is in direct proportion from the axis of rotation. Therefore, a device which is closer to the axis of rotation is responsible for the generation of fewer voxels per rotation (image refresh period) than one which lies at a greater radial distance to the axis of rotation. The devices at the greatest distance from the axis of rotation will have the greatest potential workload and those closest to the rotational axis the smallest. Thus, while the bandwidth of the interconnection between the multiplexing electronics and the optoelectronic components must be the same for all elements in the array, the total amount of data which may potentially be passed to each element during each image refresh period is will vary with the radial distance of each element from the axis of rotation. A further problem is the increasing voxel density of small radio. The optical emission devices are greatly of finite size and unacceptable densities can occur close to the axis of rotation.

In order to permit grey scale and colour mixing it is necessary to pass to each element an analogue signal the magnitude of which will determine the intensity of an illuminated voxel. The data processed by the graphics processing hardware is generally in analogue form. As the number of data pathways out of the graphics processing hardware is increased in order to facilitate parallel voxel generation within the display system, it follows that there is usually a need for a greater number of digital to analogue converters (DAC's). Normally there would be at least one such

DAC per data pathway. For example, in the beam addressed system described above the number of DAC's would normally correspond to three times the number of beams able to address the display simultaneously. The need for three DAC's per data pathway reflects the general need in the case of a beam addressed system to provide two DAC's responsible for beam deflection and one DAC for grey scale. Large numbers of DAC's considerably increase the cost, size and power consumption of the graphics processing hardware. There is a further need to pass a large volume of data across a rotating intaface. Serial methods described in the content of the Berlin device are not considered capable of effecting the anticipated transfer rates.

It is an object of the present invention to provide a high definition three-dimensional volumetric display which overcomes a number of the abovementioned disadvantages by providing a display with a substantially optically isotropic homogenous image volume which exhibits little or no obscuring aberration effects, which has data from transfer characteristics which allows serial and parallel data multiplexing in order to match the control system to the display electronics, allows a reduction in the number of DAC's and which further provides the public with a useful choice.

## Disclosure of the Invention

In one aspect the present invention provides for a three-dimensional volumetric display comprising:

a solid, substantially optically transparent support structure adapted to be rotated around an axis of rotation;

an array of optical sources dispersed through said structure, the optical sources electrically connected to a connection means which is adapted to receive control signals from display circuitry, wherein when the support dispersed array of optical sources is rotated simultaneously therewith whereupon the optical sources are illuminated in such a manner so that a three-dimensional image is generated inside the display structure.

The optical sources may be dispersed isotropically throughout the display structure.

Preferably, as the display structure rotates, the optical sources trace out circular tracks around the axis of rotation wherein the optical sources are randomly dispersed at locations on the circular tracks in such a way that the optical sources spatial density is substantially uniform throughout the display structure.

The array of optical sources may be calibrated by observing the illumination of each of the activation sources in such a way and at such a time so that their relative locations on their corresponding tracks may be determined.

In a preferred embodiment, the optical sources are located on planes perpendicular to the axis of rotation of the support structure, whereby for any single plane, the optical sources are located relative to one another on corresponding tracks so that the optical sources form a spiral when viewed along the axis of rotation, the spiral traversing a path outwards from the axis of rotation to an outer edge of the support structure.

Preferably the planes are arranged one on top of the other and sequententially displaced around the axis of rotation in relation to one another so that the optical sources lie on the surface of a helix.

In an alternative embodiment the number of optical sources on a track may vary as a function of the displacement from the axis of rotation, alternatively the optical sources on a single track may be selected to effect the emission of selected colours.

The support structure may be in the shape of right cylinder, a sphere or other three-dimensional shape suitably adapted to the viewing application for which it is intended.

The support structure may be embedded in a stationary secondary support structure, the secondary support structure having substantially the same refractive index as the support structure, the arrangement being such that there is as small a gap as possible between the support and secondary structure while allowing relative movement between the support and secondary structure whereby the construction of the secondary support structure is such that the visual isotropy of the generated three-dimensional image is enhanced.

The optical sources may be light emitting diodes, optoelectronics materials stimulated by non-visible radiation, devices which may have a two state (on/off) or three state (on/off/opaque) operating state.

Preferably the array of optical sources are connected to display electronics in such a way that they may be activated by means of parallel data which is multiplexed, where the degree of serial/parallel mixing is controllable and dependent upon matching the display to control electronics.

Preferably the operation of the display electronics should be sufficiently parallel so as to ensure that the serial data links do not restrict the system bandwidth.

Preferably, the optical sources are grouped into regions which are each driven in parallel where those regions as a whole are driven serially, each region having a number of high workload and low workload in order that each data pathway has substantially the same potential data transfer capacity, wherein the workload is proportional to the radius of the track on which the optical source(s) is located.

Preferably the rotating components of the volumetic display are coupled to stationary components by means of a multichannel optical data link.

The support structure may incorporate a reciprocating core incorporating a reduced number of optical sources the reciprocating motion when coupled with rotational motion producing a plurality of virtual tracks.

## Brief Description of the Drawings

The present invention will now be described by way of example and with reference to the drawings in which:

**Figure 1** illustrates a simplified dispersed optical source display having optical sources located on planar spiral patterns;

**Figure 2** illustrates a top view of the dispersed optical source display of Figure 1;

**Figure 3** illustrates a simplified schematic perspective view of a single plane of a dispersed optical source display;

**Figure 4** illustrates a top view of the display device shown in figure 4;

**Figure 5** illustrates detail of a calibration method appropriate for a display device of figure 4;

**Figure 6** illustrates a schematic of an N x M planar emitter array; and

**Figure 7** illustrates a representation of the dispersal of optical emitters through a display volume.

The present invention may be classified as a moving matrix type volumetric display. The closest prior art of which the applicant is aware is US patent No. 4,160,973 (Berlin).

As noted above, ideally a three-dimensional volumetric display will produce images which faithfully reproduce the object concerned without the display system producing optical artefacts resulting from the system itself.

This requires that the voxel refractive index be the same or similar as the refractive index of the volume in which the image is to be generated. The expression "the same" is understood to mean that the light emitted from the image encounters substantially identical optical conditions when traversing the display device. Therefore, in the limiting case, the physical apparatus which produces the light emissions (by means of illuminated optical sources) within the image generation volume is completely transparent and does not interfere with optical emissions produced by voxels within the swept volume.

Therefore, the ideal image generation volume is a transparent solid with a constant refractive index throughout its volume. This contrasts with swept volume scanned beam devices (such as an electron beam impinging on a phosphor screen). Here, the glass structure supporting the phosphor has a different refractive index from the rest introduces refractive aberrations when the screen is at an oblique angle to the viewer. Such aberrations are caused both by refraction distorting light from voxels as well as a total internal reflection within the glass.

To overcome these problems, a planar matrix display could be embedded in a support structure having the same refractive index as the matrix display. This would avoid refraction aberrations. However, obscuration aberrations would still be a problem because of the highly ordered arrangement of optical emission devices and their associated electrical connections.

A solution to this is to disperse the emission devices through the display volume.

Figure 1 illustrates a simplified example of a display device in which the optical sources are dispersed. Referring to figures 1 and 2, a cylindrical transparent support structure 20 contains planar arrays 15a, 15b 15c of optical sources 21a, 21b etc. For clarity, only three planes are shown spaced widely apart. The planar array construction is not intended to limit the scope of the invention and merely represents an implementation which is for convenience in manufacture and construction. Accordingly, the display can be generalised to a rotating volume containing distributed optical sources. The dispersion may be described as random insofar as randomness is interpreted to exclude statistical clustering. To illustrate the principle of dispersion of the optical emitters, Figure 7 illustrates a diagram of emitter layout in a cylindrical display system. The x and y axes correspond to a section through the cylinder with the x axis being the radial direction and the y axis the height. These axes are different from those shown in the other figures. The z axis corresponds to the track length which is proportional to the radius measured from the axis of rotation. The plane L corresponds to the track length as a function of radius and it can clearly be seen that to maintain emitter density toward the axis, and given the finite size of the emitters, there will be congestion problems near the centre. This will be discussed further below. Referring again to Figure 7, the matrix array in Solomon would be represented by the plane of emitter locations T (coplanar with the x and y axes) and the present invention emitter locations as, for example, the artside of the display, as being along the track path indicated by the letter S.

In the embodiment shown in figure 1, the optical sources are arranged in a path (lying in a plane) traversing a spiral from the axis of rotation of the display, to an outer edge. Each of the planes, upon which the optical sources are located, are rotationally displaced with respect to one another (around the axis of rotation of the support structure). Therefore, there is no preferred alignment orientation when the display volume is viewed from any direction.

A suitable dispersal regime may be where optical emitters are located at different locations along a track. While being constrained on a circular track, the emitter locations can be dispersed so that the emitter density is uniform over the whole volume of the display system. In this way there would be no preferred direction which would result in obscuration of one emitter by another. In the specific case of emitters being set out in spirals on adjacent planes, if the planes are sequentially displaced, the resulting emitter dispersion pattern will reduce (but not eliminate) obscuration. The preferred method is where the location of the emitters on the tracks (ie; their rest locations) is dispersed in such a manner that the emitters are spread evenly though the display.

Colour or gray scale capability may be included in the present implementation by locating (for example) three emitters on a track and timing their emission so that appropriate colours are produced.

The alternative, and preferred version, is that shown in figure 3. In this embodiment, the optical sources are dispersed on the planes which make up the support structure. The planes are sandwiched one on top of the other. Also, the optical sources are a uniform refractive index volume thus reducing the effect of distributing the wire/ connection array to avoid localised high density groups of related components/ structure.

There may be 'lensing' effects visible in the image due to the refractive index of the support structure when compared to air. However, under certain circumstances this may enhance the view of the image by magnification of image detail and a reduction in image interference caused by real world objects located on the opposite side of the display space. This would be most apparent in a spherical display space. In cases where the air/display relative refractive index produces unacceptable distortion, it may be possible to embed the rotating display support inside a body of similar, if not identical, refractive index. For example, a rotating spherical display volume device may be embedded in a static cubic block. The rotating and static components would be optically coupled so that there is little or no refractive gradient or interface between the two. This construction may be suitable for cases where the application requires a specifically shaped display unit. At the centre, the voxel density will be high as the paths traversed by the optical sources will be shorter than those towards the edge. The voxel density is therefore ideally reduced by decreasing the number of optical sources in the core region. This congestion will be discussed further below.

Referring again to figure 3, a single plane 24 is shown having five optical sources 25a-e. Of course, this number is illustrative only and a practical display will incorporate a large number of optical sources. As the plane is rotated around the z axis (the z axis being perpendicular to the x and y axes), each of the optical sources will trace out concentric circular paths or tracks 26. Optical sources are activated in synchronisation with the rotational motion of the support structure and voxels may therefore be positioned in the display space as required. The optical sources need to be illuminated at precisely known positions in space in order to produce an image. In the present case, the positions of the optical sources must be calibrated with reference to the rotational position of the support structure. In the case of the optical emitters located in a known dispersal regime on the tracks, calibration may be performed using the known locations of the optical sources in each plane. Alternatively, all optical sources may be simultaneously momentarily activated and normalised or rotated onto a plane passing through the axis of rotation of the support structure (or any other reference plane). Such a procedure is schematically shown in figure 5 whereby a random array of optical sources 25a-e are advanced or delayed onto corresponding locations 26a-e on the Y axis. This may be done by using a video camera imaging the display from above and using a reference optical source located on the reference plane (or other known location) and delaying the activation of other optical sources in relation to this source. The unknown optical sources delay or advances their activation so that they lie on the Y axis. Other calibration methods may be feasible and it is envisaged that the implementation of the synchronisation step would be within the scope of one skilled in the art.

The optical sources may be thought of as light emitting means powered and activated by electrical connections using wires. As a consequence of the dispersion of the optical sources within the display volume, the wires will also be dispersed and thus the display device will not exhibit any preferential obscuring aberrations. It is feasible that electrical connections may be effected by means of thin, virtually invisible, metallic fibres encased in a uniform refractive index support medium.

Referring to the data flow constraints, if we consider a planar array of N x M optical sources, the total number of connections is generally 2NM (assuming two connections per optical source or NM + 1 for a common ground). These connections can be addressed in parallel as they are completely independent. This would be effective if the data supply mechanism was able to carry NM data pathways at any one time. In this model, the connection between each graphics path line channel and each optical source would take the form of a one to one mapping. However, with the inclusion of grey scale capability or a display having a practical resolution, each optical source would require the application of an analogue voltage level and for systems having even a moderate voxel capacity, the size of the driving circuitry would be very large. For example for a display 30 cm high and 15 cm in radius, at 1 mm element separation there would be 45,000 elements. That is - 45,000 pathways without serial links. For this reason, it is highly desirable to incorporate a partially sequential data transfer method. To this end, the highly parallel array may be interconnected in a series of planes. This can be thought of as sub dividing the N x M display into a sequence of individually parallel connection arrays but with the subdivided sections being multiplexed. This would result in the number of interconnections being significantly reduced. The effect of such a reduction is the inclusion of serial activation of the elements within each 2D segment. However, it can be seen that the degree of parallelism can be adjusted to match the control system. This adjustability in the design of the volumetric display allows optimisation of the particular display to achieve a required level of definition, voxel spacing and subsequent image quality coupled with the characteristics of the control system. It is considered that the inclusion of such adaptable multiplexing represents a highly desirable attribute of the present novel system. The above multiplexing technique can be readily adapted to the dispersed optical element display.

As noted above, the size of a track swept out by an optoelectronic element is proportional to the radial distance, R, from the axis of rotation. As a consequence for elements approaching the axis of rotation i.e. for elements with decreasing values of R, there is less space to disperse these elements within the display space. Further, the potential number of voxels which each element may create during each revolution of the display space is directly proportional to the radial distance, R, of the element from the axis of rotation.

Accordingly, as the axis of rotation is approached, there is less space for element dispersal and a decrease in the potential workload for each element. This is where it can be seen that for small values of R and finite optical element size, there will be congestion. The lack of space for dispersal may cause optical problems (e.g. image distortion) should the refractive index of each element fail to properly match that of the display space material. This would be particularly so if an observer views an image component located on the opposite side of the axis of rotation to that of the observer. This problem may be minimised by reducing the density (i.e. number) of optoelectronic elements for smaller values of R.

Simply reducing the density of elements will affect the homogeneity of the display space. To circumvent this effect, a translational (or reciprocating) motion may be superimposed upon the rotational motion of the display space towards its centre. Therefore, that the display space material may consist of an outer rotational component and an inner cylindrical core.

These two materials are in close proximity and are matched in terms of the refractive index. Both rotate the outer core at speeds above the flicker fusion frequency. The inner cylindrical core also rotates, however its speed of rotation may differ from that of the outer material.

Further, the inner cylindrical core has a vibrational motion (parallel to the axis of rotation) superimposed upon it. The rotational speed of the inner core will generally be greater than that of the outer display space material. The amplitude of the vibrational motion permits each optoelectronic element to pass through a number of track positions in the Y direction. For instance, should the amplitude of the vibrational motion be sufficient to allow each optoelectronic element to pass through two track positions in the Y direction, then the number of elements required in the Y direction may be halved. This introduces the concept of virtual tracks. A virtual track may be defined as a track within the display space which does not contain its own optoelectronic element from a different position within the display space for voxel generation within the virtual track.

If, for example, an inner core radius of 5 cm is considered then an outermost element upon this inner core would in the case of no vibrational motion sweep out a distance of approximately 30 cm per display space revolution, and given a voxel spacing of 1 mm, would be responsible for generating 300 potential voxels. If the density of elements is halved by the imposition of vibrational motion it would be necessary to have a vibrational motion of at least 300 times the rotational frequency of the display space. The vibrational amplitude being in the order of 3-4 mm for an inter-voxel spacing in the Y direction of approximately 1 mm. It is noted that by increasing the rotational frequency of the inner core it is possible to reduce the vibrational frequency.

The vibrational motion could be effected by various means such as by electromechanical stimulation or could be derived from the difference in rotational speed between the outer display space and inner core. Increasing the amplitude of motion would permit a further reduction in the number of optoelectronic elements required in the Y direction, i.e. parallel to the axis of rotation.

The display space material as a whole may also be flexible and highly controllable thus permitting the vibrational motion to extend from the outside to the inside at an ever-increasing amplitude. This avoids the discontinuity caused by the outer core and the inner vibrating core envisaged above.

As noted above, the present invention provides a method and apparatus for parallel voxel generation and permits a large number of voxels to be generated during each image refresh or display space revolution. An important aspect of the implementation upon coupling the voxel data from the graphics engine or control system into the display space for passage to the electro-optical elements. Should this link simply take the form of a serial optical connection, then it is likely, given the large number of elements which are contained in the display space, that only a fraction of them could be addressed/updated during each display space revolution or image refresh. That is - a serial optical link would limit the bandwidth of the connection between the graphics engine and the display space electro-optical element multiplexing system. In order to maintain a high bandwidth connection and permit a very large fraction of the elements to be updated (if not potentially all) during each display space rotation, the present invention may use a parallel optical connection between the static outside world and the rotating/vibrating display space.

In a preferred embodiment, this connection takes the form of two concentric cylinders. One of these cylinders is stationary and the other co-rotates with the display space. Upon the surface of the stationary cylinder is a 2D array of light-emitting devices and on the rotating cylinder is a 2D array of optical receptors each capable of converting light signals received from the emitters into electrical signals. Both cylinders are positioned around the axis of rotation of the display space. The principle of operation is best considered by imagining oneself to be a light receptor. The physical layout of the transmitters would cause an observer (receptor) to see a series of light sources rising and sinking in sequence. During certain periods no light source would be visible to the observer. During periods where the light source is sufficiently strong, the controlling hardware would modulate the light source in order to permit transmission of information from the source to the observer. The physical arrangement of the light sources and receptors is such as to ensure that a maximum number of light sources are able to transmit at any time to a maximum number of receptors. The use of a plurality of transmitters and receptors permits parallelism in data transfer. If a single ring of transmitters and receptors is considered (this ring being located around the circumference of the cylinders) then one can clearly and receptors together with their spacing and any collimating system placed around each receptor, we can vary the degree to which parallel data transfer may take place. By duplicating these single rings of transmitters and receptors along the length of the two cylinders we can duplicate the degree of parallelism. It is noted that these rings may be physically displaced around the circumference.

In order to effect proper data transfer it is necessary for the controlling hardware to direct (route) information to the appropriate transmitters and to have a clear knowledge of which receptor will contain the transmitted information. The system therefore employs an optoelectronic synchronisation link from which routing information can be derived and which further provides the control system with timing information which is necessary in order to generate images within the display space (see International Application PCT/NZ93/00083). The optoelectronic link takes the form of a single transmitter and single receptor, the transmitter being located upon the cylinder containing the 2D array of optoelectronic receptors and the electro-optical receiver being located upon the cylinder containing the 2D array of electro-optical transmitters. The transmitting device operates continuously and provides the receptor with a single-pulse high revolution of the display space which corresponds to a single rotation of the cylinder equipped with the optoelectronic receivers. This pulse is used to obtain timing information for voxel output into the display space and further routing information for the passage of information through the optoelectronic parallel data transfer link.

In order to tolerate a small degree of mechanical misalignment in the positioning of the electro-optical transmitter and receiver arrays. It is desirable to have a degree of duplication in the information which is passed through the parallel data transfer link and intelligent hardware which co-rotates with the display space and which is capable of performing amalgamation of incoming data, error correction and which is multiplexing of signals to the voxel elements. It is further noted that in order to achieve maximum bandwidth through the parallel data transfer link it is highly desirable to minimise on the extent of the night times. These are periods in which no transmitter is able to pass signals to any particular receptor (this being caused by the geometrical arrangements between the two arrays and corresponds to no transmitter having risen sufficiently above a receptors horizon (collimated horizon)). As a transmitter moves above a receptors horizon not only must it be aware of which receptor it is to encounter, but it must also be aware of the time at which it has risen sufficiently in order that a signal of sufficient amplitude can be received by the receptor. In one particular embodiment each transmitter will judge from information gained from the once-per-revolution synchronisation signal at what point it should commence transmitting information to a particular receptor and at what point it should stop. Between these two periods the transmitter will transmit an integral number of voxel descriptors. By exercising caution in terms of the amount of signal required by a receptor to receive the transmitted information without error. It can generally be assured that error correction will not be necessary. This however reduces the useable bandwidth of each transmitter and receiver. The degree of parallelism exhibited by the parallel data transfer link enables however a sufficiently high bandwidth for the passage of information to the display space hardware and will enable the possibility of a high percentage if not all of the voxel element positions to be updated during the course of each image refresh period.

As noted above, the present invention is not limited to a cylindrical support structure and other geometries such as spherical, conical or other rotationally symmetrical body are to be considered within the scope of the invention.

It can be seen that the present invention provides for a substantially optically isotropic and homogenious image generation volume as well as the capability of connection regime which may be adjusted in terms of the degree of multiplexed serial/parallel mixing so as to match the control system.

Either the dispersed optical source regime or other arrangements may be particularly adaptable to manufacture as a large number of identical planar optical source arrays can be manufactured from which the (in the present case) cylindrical support structure can be built up by placing one layer upon the other. Each plane may be rotated randomly to produce the dispersed scattering of the optical sources through the display volume. In the case of a spiral optical source array, offsetting adjacent planar elements would lead to a random helical surface sweeping out an image volume.

Where in the foregoing description reference has been made to elements or integers having known equivalents, then such equivalents are included as if they were individually set forth.

Although the invention has been described by way of example and with reference to particular embodiments, it is to be understood that modifications and/or improvements may be made without departing from the scope of the appended claims.

**CLAIMS:**

1. A three-dimensional volumetric display comprising:

a solid, substantially optically transparent support structure adapted to be rotated around an axis of rotation;

an array of optical sources dispersed through said structure, the optical sources electrically connected to a connection means which is adapted to receive control signals from display circuitry, wherein when the support dispersed array of optical sources is rotated simultaneously therewith whereupon the optical sources are illuminated in such a manner so that a three-dimensional image is generated inside the display structure.

2. A display as claimed in Claim 1 wherein the optical sources are dispersed isotropically throughout the display structure.

3. A display as claimed in any one of the Claims 1 or 2 wherein the display structure rotates, the optical sources trace out circular tracks around the axis of rotation wherein the optical sources are randomly dispersed at locations on the circular tracks in such a way that the optical sources spatial density is substantially uniform throughout the display structure.

4. A display as claimed in any preceding claims wherein the array of optical sources are calibrated by observing the illumination of each of the activation sources in such a way and at such a time so that their relative locations on their corresponding tracks may be determined.

5. A display as claimed in any preceding claim wherein the optical sources are located on planes perpendicular to the axis of rotation of the support structure, whereby for any single plane, the optical sources are located relative to one another on corresponding tracks so that the optical sources form a spiral when viewed along the axis of rotation, the spiral traversing a path outwards from the axis of rotation to an outer edge of the support structure.

6. A display as claimed in any preceding claim wherein the planes are arranged one on top of the other and sequententially displaced around the axis of rotation in relation to one another so that the optical sources lie on the surface of a helix.

7. A display as claimed in any one of the claims 1 to 5 wherein the number of optical sources on a track varies as a function of the displacement from the axis of rotation, alternatively the optical sources on a single track may be selected to effect the emission of selected colours.

8. A display as claimed in any preceding claim where the support structure may be in the shape of right cylinder, a sphere or other three-dimensional shape suitably adapted to the viewing application for which it is intended.

9. A display as claimed in any preceding claim wherein the support structure is embedded in a stationary secondary support structure, the secondary support structure having substantially the same refractive index as the support structure, the arrangement being such that there is as small a gap as

possible between the support and secondary structure while allowing relative movement between the support and secondary structure whereby the construction of the secondary support structure is such that the visual isotropy of the generated three-dimensional image is enhanced.

10. A display as claimed in any preceding claim wherein the optical sources are light emitting diodes, optoelectronics materials stimulated by non-visible radiation, devices which may have a two state (on/off) or three state (on/off/ opaque) operating state.

11. A display as claimed in any preceding claim wherein the array of optical sources are connected to display electronics in such a way that they may be activated by means of parallel data which is multiplexed, where the degree of serial/parallel mixing is controllable and dependent upon matching the display to control electronics.

12. A display as claimed in any preceding claim wherein the operation of the display electronics is sufficiently parallel so as to ensure that the serial data links do not restrict the system bandwidth.

13. A display as claimed in any preceding claim wherein the optical sources are grouped into regions which are each driven in parallel where those regions as a whole are driven serially, each region having a number of high workload and low workload in order that each data pathway has substantially the same potential data transfer capacity, wherein the workload is proportional to the radius of the track on which the optical source(s) is located.

14. A display as claimed in any preceding claim wherein the rotating components of the volumetic display are coupled to stationary components by means of a multichannel optical data link.

15. A display as claimed in any preceding claim wherein the support structure may incorporate a reciprocating core incorporating a reduced number of optical sources the reciprocating motion when coupled with rotational motion producing a plurality of virtual tracks.

16. A display substantially as been described with reference to the accompanying figures.

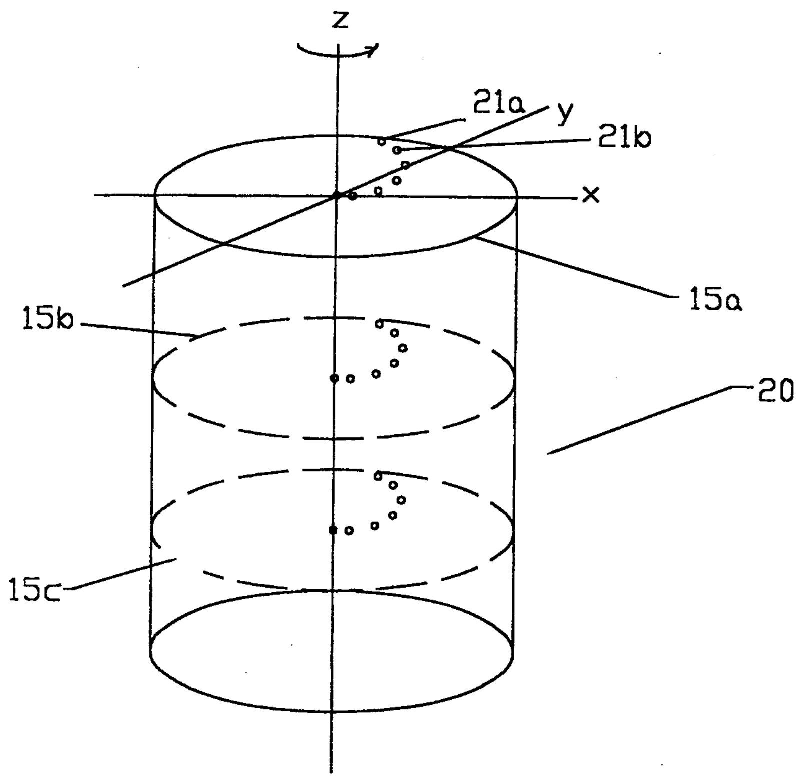



Fig 1

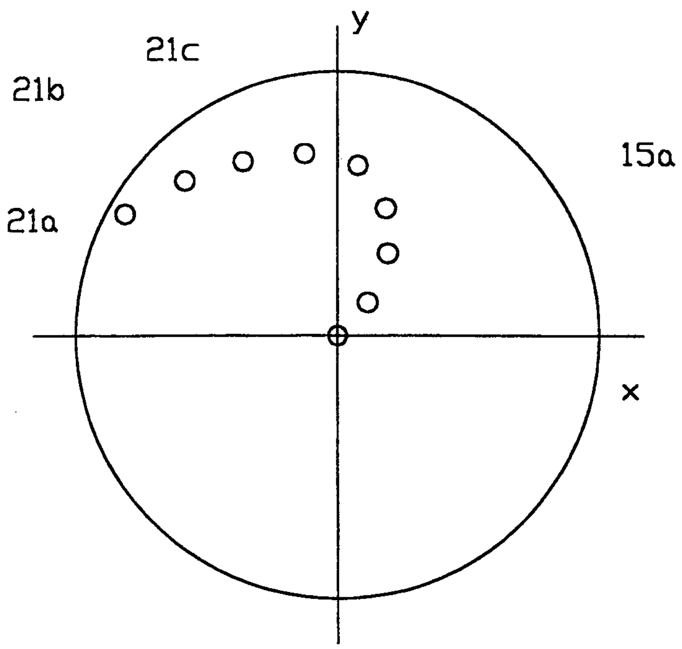



Fig 2

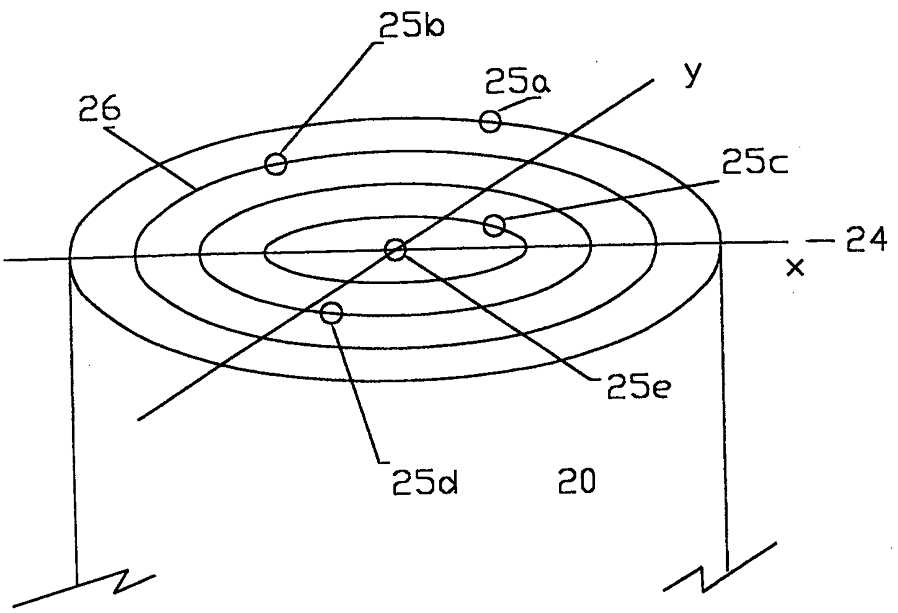



Fig 3

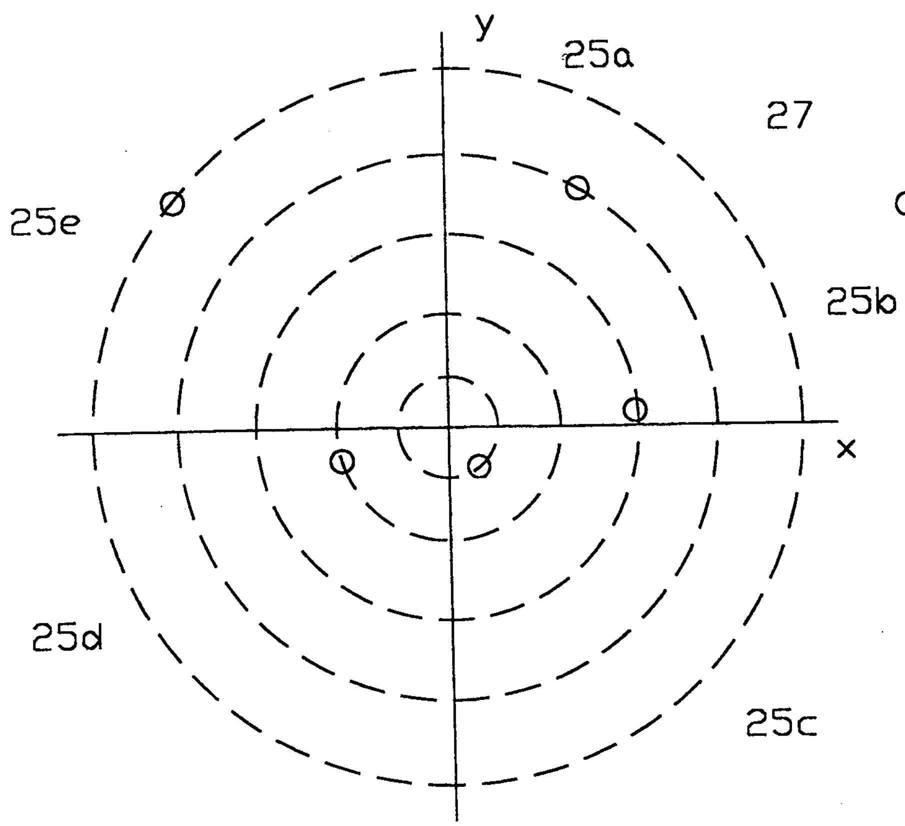
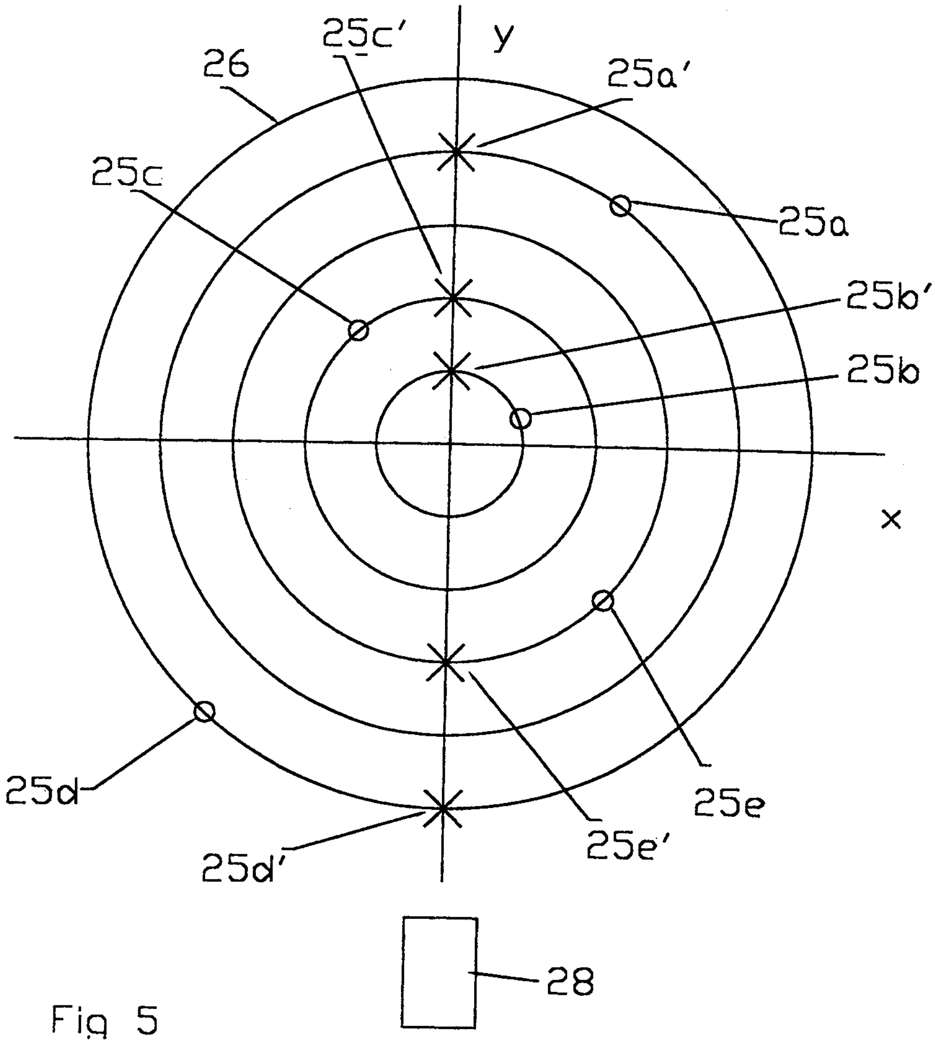
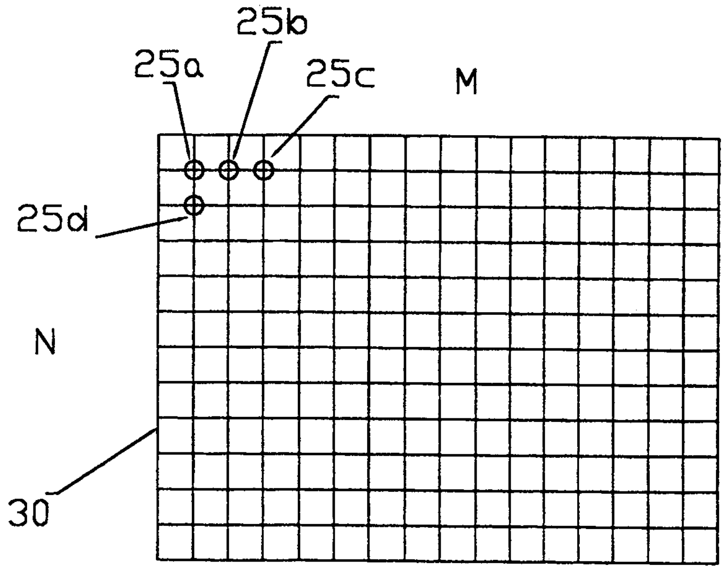



Fig 4



y
26
25c'
25a'
25c
25a
25b'
25b
x
25d
25e
25d'
25e'
28


Fig 5



25b
25a
25c
M
25d
N
30


Fig 6

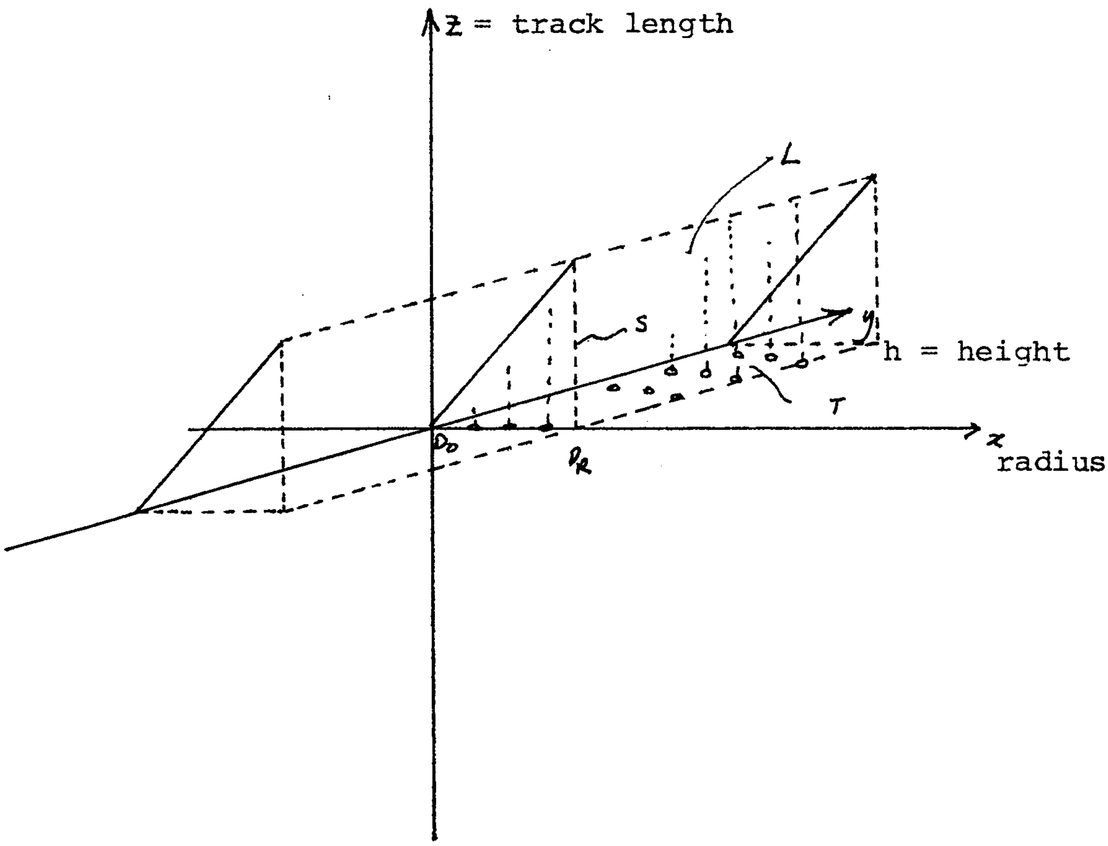



Fig 7

**INTERNATIONAL SEARCH REPORT**

International application No.
**PCT/NZ 99/00072**

| **A.** | **CLASSIFICATION OF SUBJECT MATTER** |
|---|---|
| Int Cl$^6$: | G09F 19/12, G09G 3/14, G02B27/22 |

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
G09F 19/00, 19/02, 19/12, G09G 3/-, G02B 27/22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT: 3D, 3 dimension:, three dimension:, spin:, rotat:, axis.

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| | US 4 160 973, A (Berlin, Jr) 10 July 1979 | |
| X | Column 2, line 35 - column 4, line 38 | 1 - 4 |
| A | | 5 - 16 |
| A | US 5 148 310, A (Batchko) 15 September 1992 | 1 - 16 |
| A | EP 470 801, A (Texas Instruments Incorporated) 12 February 1992 | 1 - 16 |

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 8 November 1999 | 12 NOV 1999 |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INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ 99/00072

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | EP 418 583, A (Texas Instruments Incorporated) 27 March 1990 | 1 - 16 |

## INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
**PCT/NZ 99/00072**

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

| Patent Document Cited in Search Report | | Patent Family Member | | | | | |
|---|---|---|---|---|---|---|---|
| EP | 470 801 | JP | 6 130 904 | | | | |
| EP | 418 583 | US | 5 082 350 | US | 5 172 266 | US | 5 024 494 |
| | | CA | 2 023 438 | JP | 3 206 794 | | |

END OF ANNEX