

## **FELIX 3D Display: An Interactive Tool for Volumetric Imaging**

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### **ABSTRACT**

The FELIX 3D Display belongs to the class of volumetric displays using the swept volume technique. It is designed to display images created by standard CAD applications, which can be easily imported and interactively transformed in real-time by the FELIX control software. The images are drawn on a spinning screen by acousto-optic, galvanometric or polygon mirror deflection units with integrated lasers and a color mixer. The modular design of the display enables the user to operate with several equal or different projection units in parallel and to use appropriate screens for the specific purpose. The FELIX 3D Display is a compact, light, extensible and easy to transport system. It mainly consists of inexpensive standard, off-the-shelf components for an easy implementation. This setup makes it a powerful and flexible tool to keep track with the rapid technological progress of today. Potential applications include imaging in the fields of entertainment, air traffic control, medical imaging, computer aided design as well as scientific data visualization.

The FELIX 3D project team has evolved from a scientific working group of students and teachers at a normal High School in Germany. Despite minor funding resources within this non-commercial group considerable results have been achieved.

**Keywords:** 3D display, volumetric display, autostereoscopic display, laser projection display, three-dimensional imaging, voxel, FELIX, air traffic control, CAD

### **1. INTRODUCTION**

The implementation of a HOLODECK like display device is a long held dream of researchers in computer graphics and interactive techniques. There has always been a desire in technology and science not only to recognize in a three-dimensional manner the interrelation of our three-dimensional world, but also to display it dynamically, in real time, interactively, in true color and in natural geometry. The fast development of computer graphics has turned this desire into an expectation. Traditional 2D displays like cathode ray tubes (CRT) or liquid crystal displays (LCD), in which 3D pictures can be rendered are most popular for a wide range of applications. These systems however display the spatial information from the perspective of only one viewer.

For an ideal dynamic 3D image representation a technique should be preferred with a multiple user, all-round view capability, without requiring visual aids. It should also satisfy all depth cues such as stereo vision and motion parallax. Volumetric displays, which generate 3D images within a physical volume rather than on a stationary surface, meet most of these needs. The images are thus placed within the physical world of the observer, in comparison to virtual reality systems where the observer is placed within the virtual environment of the non-physical image space. Already since the 1940s various methods have been investigated to develop a volumetric 3D display. But technology limits made the

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immediate implementation impossible. Recent advances in hardware and software technology provide new chances for near-term operational concepts for certain applications. The volumetric 3D display technology will provide an important option for team tasks and tasks requiring many simultaneous views of real-time or multidimensional data.

The development of our FELIX 3D Display refers to the well-known swept-volume technique, which is characterized by its comparatively simple system configuration. Compared to other approaches the FELIX display is a compact, light, and easy to transport system of modular design. As it consists of standard components, the display is also inexpensive and easy to maintain.

In the following sections we will illustrate the past and present developments in the field of volumetric imaging by selecting representative examples for different approaches. Furthermore, we will introduce our FELIX 3D Display with its unique features as a part of these efforts. This will be followed by a discussion of a design study for an appropriate 3D input device in six degrees of freedom to interact with the display content. Finally we will briefly introduce some potential applications for this innovative 3D display device.

## 2. BASIC CONCEPTS OF VOLUMETRIC IMAGING

To produce volumetric images, it is necessary to create a display volume of some type within which the image may be drawn. A number of attempts to achieve this goal have been made in several past and current development efforts. Generally these attempts can be divided into two basic categories:

- swept volume displays,
- static volume displays.

Figure 2 gives an overview of the basic classes with examples, which do not claim to be complete. Some approaches of related developments will be described in more detail in the following sections. Holographic techniques are not discussed in this paper as they represent a separate class of its own.

### 2.1 Swept volume displays

In the case of swept volume displays, the display volume is created by the mechanical motion, either vibrational or rotational, of a target screen. A periodically time-varying two-dimensional (2D) image is used to sweep out the volume cyclically at a frequency higher than the eye can resolve. Eventually a spatial image is formed through persistence of vision. Thus several of the usual cues of everyday depth perception are exhibited, especially the compelling ones of stereopsis and parallax.

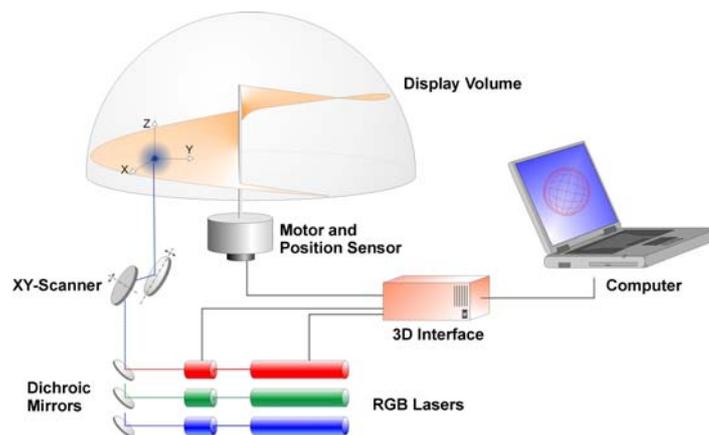


Figure 1: FELIX 3D Display: Laser projection on a helical screen

The primary 2D pattern may be generated on either an emissive panel or a passive projection screen. The depth effect is achieved when the screen surface, which can take various shapes, is oscillated perpendicularly to itself, or when it is rotated, in synchronism with the cyclic 2D pattern. The screen serves as a plane with which a volume is scanned in

order to provide a three-dimensional blackboard or raster upon which various spatial patterns may be written. Alternatively, the screen may be fixed but viewed in an oscillating plane mirror, which has a similar effect.<sup>24</sup>

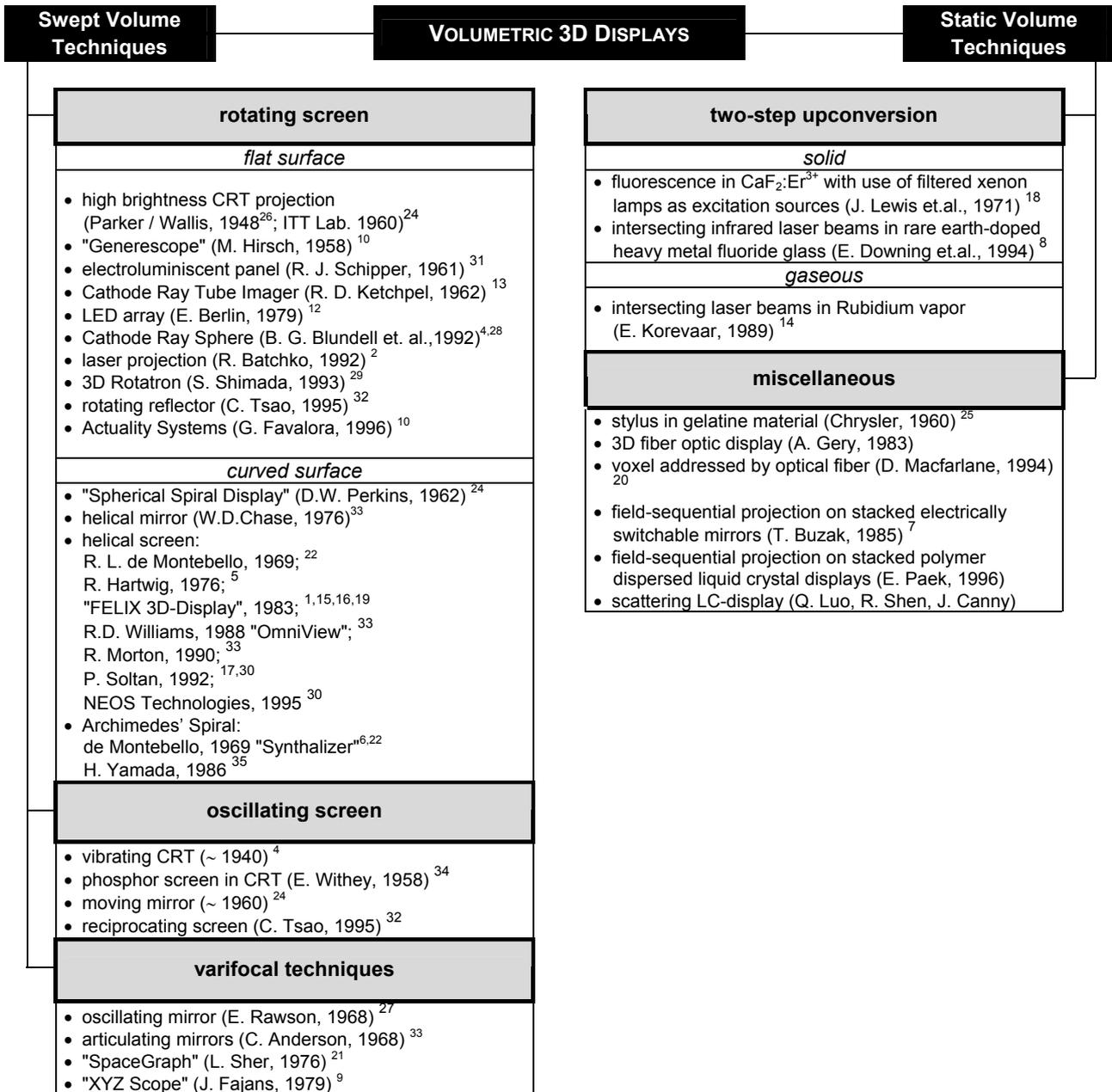


Figure 2: Overview of volumetric imaging techniques

Most attempts to create volumetric 3D images are based on swept volume techniques, because they can be implemented in the near term with today's hard- and software. For this reason we also use this approach in our setup as shown in Figure 1. For simplification the sketch is reduced to only one projection unit (in this case a galvanometric unit), illuminating only one part of a single turn helix. As a representative of the category of swept volume techniques, we describe the general principle of operation used in our 3D display FELIX.

In 1983 we started investigations on volumetric imagers which led to the development of the "FELIX 3D Display".<sup>1,15,16,19</sup> This system, like several others, refers to the concept of projecting laser images on a rotating helical screen as suggested by R. Hartwig (Figure 8).<sup>5,30</sup> Our investigations in this field mainly focus on different screen shapes, a modular and portable setup, advanced projection techniques and software development.

In the FELIX approach the primary 2D pattern is generated on a passive projection screen. The rotating helix sweeps out a cylindrical envelope, providing a volumetric display medium through which scanned laser pulses are projected. The hitting laser beam will be scattered from the rotating surface causing a visible light spot (voxel = volume pixel). The spatial position of the emanating voxel within the display is determined by the momentary location of the laser beam's intersection with the rotating helix (Figure 1).

In the following paragraphs further examples illustrate different swept volume approaches.

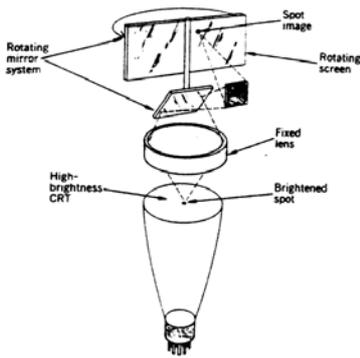


Figure 3: CRT projection on rotating screen (ITT, 1960)<sup>27,24</sup>

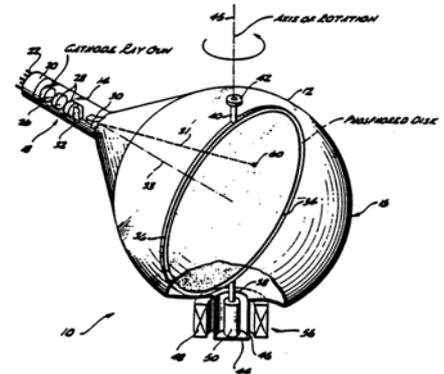
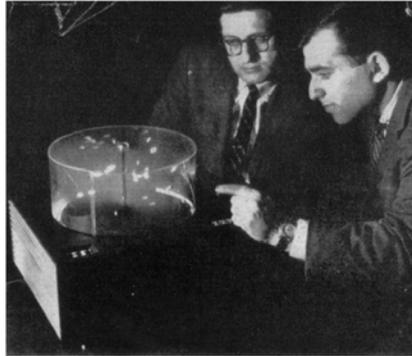


Figure 4: Rotating phosphor disk in CRT (R. Ketchpel, 1962)<sup>33</sup>

One of the early techniques, presented by the ITT Laboratories in 1960, consists of an especially programmed high brightness cathode ray tube (CRT) whose blips are optically transferred to a translucent rotating screen within a glass cylinder (Figure 3).<sup>24</sup> Later Robert Batchko described a similar system where he used a vector-scanned laser illumination source instead of a CRT.<sup>2</sup> Inspired by these research activities Gregg Favalora (Actuality Systems, Inc.) recently set up a volumetric display, implementing state-of-the-art hard- and software. A high resolution projection engine illuminates a diffuse projection screen that rotates with projection optics and corresponding relay mirrors.<sup>10</sup>

In another arrangement, introduced by R. Ketchpel in 1962, a phosphor-coated flat screen rotates in a vacuum, with a controlled electron beam striking its surface (Figure 4).<sup>13,23</sup> Based on this technology B. Blundell, A. Schwarz et. al. from the University of Canterbury (Christchurch/New Zealand) presented a volumetric display, called "Cathode Ray Sphere CRS", in 1992.<sup>1,4,28</sup>

Figure 5 shows a volume display system developed by E. Berlin at MIT. He proposed using an active 2D matrix of light emitting diodes (LEDs) with the display electronics residing on the rotating matrix.<sup>6,12,31</sup>

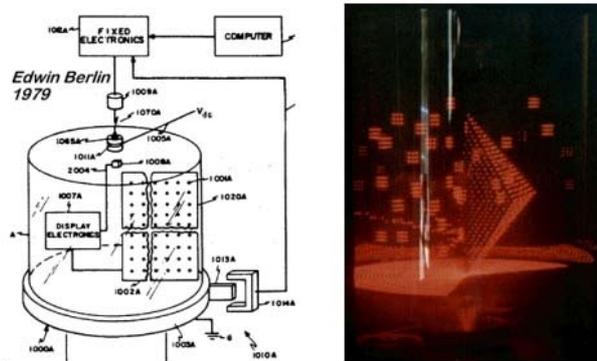


Figure 5: Rotating LED array<sup>12</sup>

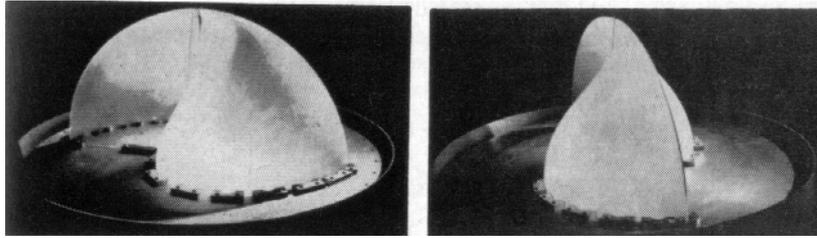


Figure 6: Spherical Spiral Display (D. W. Perkins, 1962)<sup>24</sup>

An early approach using a curved moving surface was described in 1962 by D. W. Perkins. He introduced the "spherical spiral display" with a specially shaped screen that rotates about its vertical axis and onto which a light beam is projected from below by an optical system (Figure 6).<sup>24</sup> The intention was to use it as a 3D radar display.

Another space-filling display method is the "Synthalizer" invented by de Montebello in 1969. Images on a film strip are projected onto a rotating translucent drum which is composed of elements in the shape of an Archimedes' Spiral (Figure 7).<sup>6</sup>

Instead of using a spiral, de Montebello alternatively proposed to use a projection screen in the form of a helix that rotates around its vertical axis.<sup>22</sup>

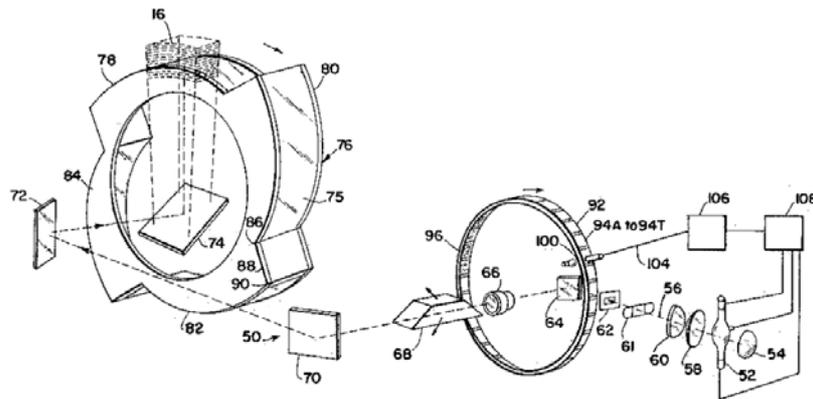


Figure 7: "Synthalizer" - projection on a rotating Archimedes' spiral (R. L. de Montebello, 1969)<sup>22</sup>

The concept of laser projection on a rotating helical screen was presented by R. Hartwig in 1982 as shown in Figure 8.<sup>5</sup>

In 1988 R. D. Williams and F. Garcia demonstrated a display wherein a scanned laser beam is displayed upon a continuously rotating disc that is mounted on a motor shaft at an angle. Later they also employed a helical surface in their device further known as the "OmniView 3D Display".<sup>33</sup>

Since early 1990 a research team (P. Soltan, M. Lasher et. al.) at NRaD, the RDT&E Division of the Naval Command, Control and Ocean Surveillance Center (NCCOSC, San Diego), in cooperation with NEOS Technologies, works on a similar development as well using a helical surface.<sup>17,30</sup>

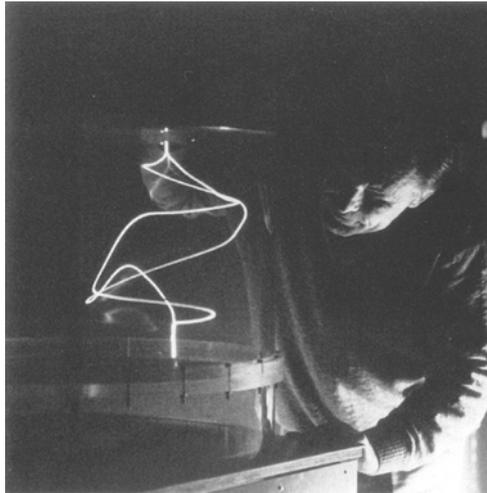


Figure 8: Laser projection on a rotating helical screen (R. Hartwig, 1982)<sup>5</sup>

Another attempt to create three-dimensional images is the varifocal technique.<sup>27</sup> In this method, the focal length of a spherical mirror membrane is varied between an image source and a viewer at a rate above the image-integration frequency. The varifocal techniques are not strictly volumetric as they produce virtual images. Besides they have a limited viewing zone and the images are not distortion free at some angles.

## 2.2 Static volume displays

Systems which are able to create a display volume without the need to employ mechanical motion are classified as static volume displays. The goal of this technique is to provide emissive voxels at a large number of locations in a static setup incorporating no oscillating or rotating parts. Several interesting attempts have been made using transparent crystals, gases, electronic field sequential techniques, and others. However, current technology limits make the near term implementation of large scale displays difficult.

The phenomenon of stepwise excitation of fluorescence seems to be one suitable approach for the generation of isolated fluorescent voxels. This physical effect has been known since the 1920s, when it was first observed in mercury vapor. The process occurs in the presence of radiation of two distinct frequencies, each of which is resonant with an electronic transition.

Based on the pioneering work of J. D. Lewis et. al. of Batelle Laboratories in 1971, E. Downing et. al. at Stanford University, presented in 1994 a three-color 3D display with improved upconversion materials using high power infrared laser diodes.<sup>8,18</sup> Another approach, patented by E. J. Korevaar in 1989, used a gaseous volume enclosed in a sealed glass container.<sup>14</sup> Since 1999 the FELIX 3D project team is also investigating a static volume approach based on fluorescence excitation in a rare earth-doped crystal. Initial tests with our experimental setup, called "Solid FELIX", revealed promising results (Figure 9).

Apart from the described technologies several other interesting attempts have been made in the field of static volume displays. Early approaches from the beginning of the 1960s proposed the mechanical insertion, support, and translation of objects or particles in a volume. E.g. a stylus which can write in three colors was suspended in a tank of transparent gelatin. The servo-driven stylus moves through the gelatin, leaving a colored trace (Figure 10).<sup>25</sup>

An alternative static volume procedure, suggested by D. Macfarlane in 1994, proposed to use a three-dimensional stack of volume elements, made of an UV-cured optical resin doped with an organic dye. Each voxel is addressed by an optical fiber that pipes light to the voxel.<sup>20</sup>



Figure 9: Design study of the SOLID FELIX display



Figure 10: Stylus leaving a trace in transparent gelatin<sup>25</sup>

### 3. MODULAR FELIX 3D DISPLAY SYSTEM ARCHITECTURE

The FELIX 3D Display (Figure 11) is a compact, light, extensible and easy to transport system of modular design. It consists of the following main components:

- display volume containing the projection screen,
- projection units with integrated lasers,
- projection unit drivers and motor power supply,
- control PC with 3D interface.

The core element of the system is a rotating target screen that sweeps out the display volume enclosed by an acrylic half-sphere. Appropriate screen shapes (e.g. helical shapes) can be used for the specific purpose of the application. The 2D image, projected onto the target screen, is generated by one or more projection units from below the display volume. A projection unit consists of a light source and a XY scanning system. As a light source we use a monochromatic laser as well as a laser-based red-green-blue (RGB) color mixer. Depending on the application we use different types of scanning systems.

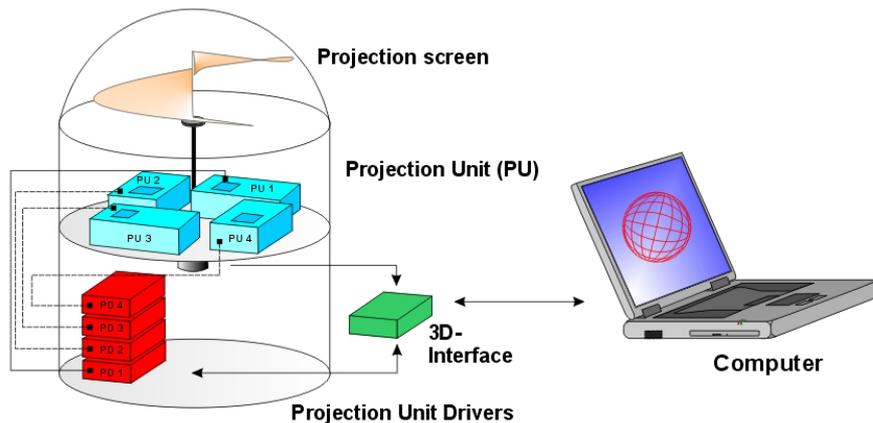


Figure 11: Modular system architecture of the FELIX 3D Display

To create three-dimensional objects in the addressable display volume, the imaging components are synchronized by a 3D interface. Among other components it contains a frame buffer and motor control electronics. The frame buffer is a special PC card that stores the image information and sends xy position signals to the projection unit drivers. This

hardware provides high data rates appropriate for state-of-the-art fast and high resolution scanning devices. The motor control electronics synchronize the projection screen's position with the frame buffer output.

The imaging software runs on a PC and is written in C++. Graphics can be imported as AutoCAD DXF files or the user can create three-dimensional geometry from scratch. Existing geometry can be manipulated in several ways (rotation, translation, zoom, animation). Solid surfaces cannot be displayed reasonably, because of the transparent nature of the image.

### 3.1 Projection techniques and Projection Unit Design

In the following sections a projection technique describes the way the two-dimensional image is projected onto the rotating target screen.

Each application puts special demands on the graphics to be displayed. To satisfy these requirements one or a combination of the following three projection techniques is implemented:

- vector graphics
- raster graphics
- random access graphics

We implemented each of these techniques by applying specially designed projection units as described in the following sections.

The modular design allows the use of multiple projection units either partitioning the display volume or with superimposed projection areas to increase the number of voxels in the display volume (resolution). This will also increase the level of detail of the generated image. Compared to CRTs the resolution of volumetric displays in each layer is still low. But emerging technologies like Digital Light Processing (DLP™) or spatial light modulators (e.g. Digital Micromirror Devices DMD™), promise future improvements in the field of volumetric imaging, too.

#### 3.1.1 Vector graphics with galvanometric scanners

Employing vector graphics (Figure 12), spatial images are created which consist of polygon lines instead of single voxels. Objects are drawn as a combination of daisy-chained lines onto the rotating projection screen. The third dimension of the generated line graphics is given by the continuous movement of the screen. We implemented this technique with two perpendicularly arranged galvanometric scanners. A disadvantage of this scanner type is its

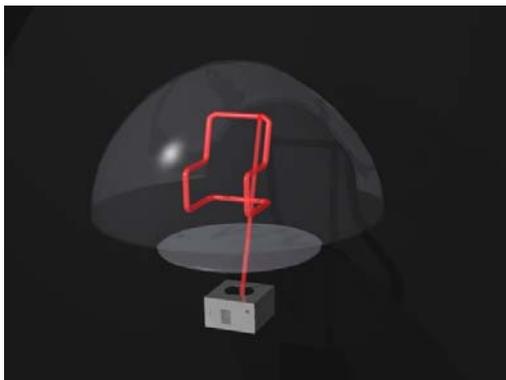


Figure 12: Principle of 3D vector graphics

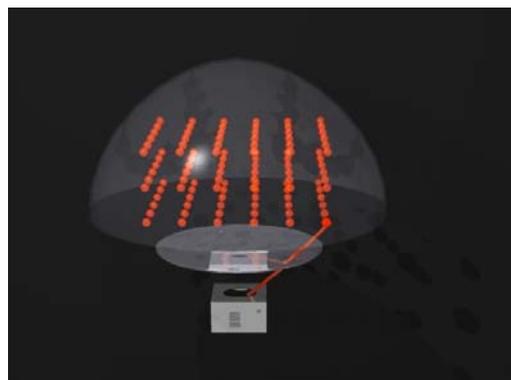


Figure 13: Principle of 3D raster graphics

mechanical inertia limiting the number of lines that can be displayed to a few hundred, which is still enough for show purposes. Despite the limited spectrum of objects, which can be displayed, the advantage of this implementation is the quite easy realization of a multicolor display, by mixing modulated red, green and blue laser beams (Figure 1).

### 3.1.2 Raster graphics with a polygon-galvanometric scanner

In our raster graphics implementation (Figure 13) the image volume is filled with a fixed three-dimensional array of voxels, made up of forty equidistant, stacked planes. In each plane the voxels are lined up in a raster similar to the pixels on a CRT. A high speed polygon scanner draws horizontal lines and a galvanometric scanner deflects the beam orthogonally to these lines. Synchronization electronics provide a stable raster. One advantage of this implementation is the quite simple image generation for the computer. It only has to modulate the laser beam in an adequate way. By using three lasers (RGB) and three modulators we simply achieve a colored image.

### 3.1.3 Random access graphics with acousto-optic deflection system

Random access graphics (Figure 14) are also based on a fixed array but only the voxels to be displayed are scanned. The majority of volumetric images displayed in laser-based swept volume displays require only a fraction of the addressable space. Therefore the random access graphics approach saves data resources and reduces the amount of data which must be transmitted to the projection unit. To implement this technique we use an acousto-optic XY-deflection unit, which is based on the diffraction on an internal crystal grating of the incident laser beam. The crystal grating is varied to get different deflection angles. This variation takes a constant access time, in our case  $5\mu\text{s}$ , which leads to a resolution of up to 200,000 voxels per second. One disadvantage of acousto-optic scanners is that beam deflection is wavelength-dependent. For a multicolor setup it is therefore necessary to use one deflector for each basic color. However, it is much faster than galvanometric scanners because it has no moving parts. Additionally, the free choice of the coordinates of the voxels facilitates to display relevant areas of the volumetric image with higher voxel density, which means in a higher resolution.

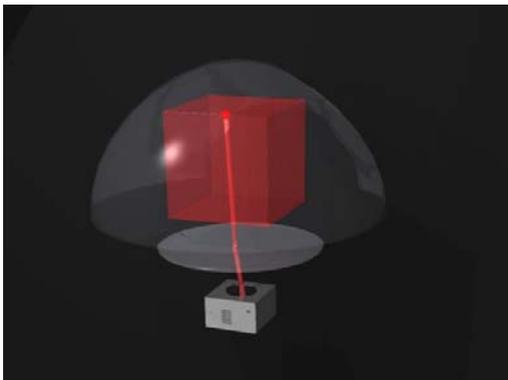


Figure 14: Principle of 3D random access graphics



Figure 15: Three-dimensional vector and random access graphics in the FELIX 3D Display

Figure 15 shows a photograph of a colored vector graphic on the left hand side and a random access graphic of an aircraft on the right hand side.

## 3.2 Screen design and hidden zones

In our modular FELIX display we investigated different kinds of rotating helical shaped screens. The rotating screen technique facilitates a simple hardware configuration with an easier mechanical and optical construction than an oscillating approach. Also evacuation is not necessary since the trapped air moves along with the screen. An easy to change mechanism allows to use appropriate screens for specific purposes of applications. The two investigated helical shapes are a double turn helix and a single turn helix (Figure 16). A disadvantage of helical shapes is the presence of

- occlusion zones, where sections of the image are hidden from the viewer by parts of the screen or the axis
- dead zones in the display volume that are not addressable by the imaging beam.

In the FELIX 3D Display rotation axis and the motor are located below the projection screen. As a result we would have a dead zone where the axis blocks parts of the projection. This is avoided by employing multiple projection units placed around the axis and thus partitioning the image volume.

The displayed image can be seen from almost any angle only with a few occlusion zones. In these zones sections of the image are hidden from the viewer by parts of the rotating helix or the axis. Number and size of the occlusion zones depend on the surface's shape and are quite severe with the double helix system. To minimize occlusion zones we plan to investigate a half-turn helix.

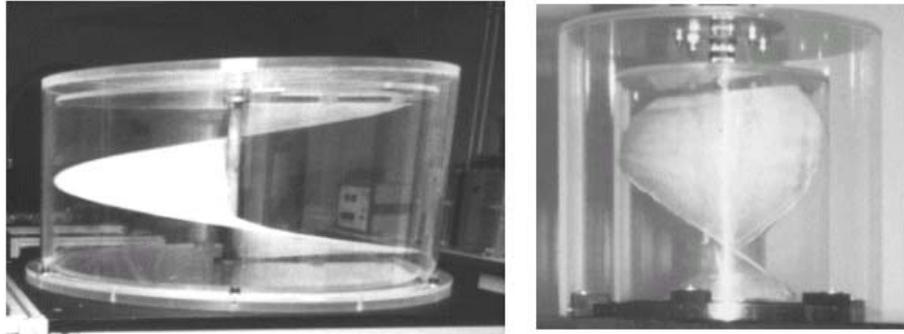


Figure 16: Investigated single turn helix and double helix

Another disadvantage of the double helix is the required precision to manufacture the projection screen. As the image will be refreshed each half rotation cycle both screen halves have to coincide exactly. Slight asymmetries in the shape lead to discontinuities in the generated image. With a rotation frequency of 10 Hz an image refresh rate of 20 Hz is achieved. As compared to the single turn helix only half the motor speed is required. Though being a mechanical advantage at a first glance, the slow rotation of the screen disturbs the visual perception.

#### 4. DESIGN STUDY OF A NEW 3D INPUT DEVICE

To open the third dimension in display technology means to open a new dimension in input-device-design as well. The intention to bring FELIX to full 3D-operational status requires an object, capable of accepting commands in three lateral and three rotational degrees of freedom (DOF). In the next two sections we will give a rough overview of existing technologies followed by an introduction of our design study for the new input device.

##### 4.1 Existing Input Device Technology

The well known CRT monitor, featured as desk-decoration in almost any office, works on two-dimensional display technology. Accordingly input devices accept commands in two dimensions only and allow only two degrees of freedom directly.

One can distinguish between way-way-proportional (wwp) and way-speed-proportional (wsp) techniques within these elements. The wwp-input devices translate a distance in direct proportion to a distance. There may be filters to estimate the acceleration of the commanded distance and enlarge the factor of proportion, but the principle can be reduced to wwp-character. Typical wwp-input-devices are: mouse, trackball, touchpad, etc.. The mouse has a highly perceivable function to the user. Any move on the desk in relation to the mouse's main-axis is represented by a motion of the graphic-input-symbol (GIS) in the rectangular coordinate system on the screen in upright orientation. There is a direct tactile feed-back to the user, even extremely precise operation is possible. The trackball is technically a head-over-heels mouse. The user operates a ball, sensors pick up the distance and direction of the command. The main difference on the user side is the no longer direct relation of way-to-way, but a rotation-to-way transition. Nevertheless it is still a wwp-input device with a tactile feedback rated even more precise than one finds with the mouse.

The second sort of input devices follow the wsp-principle. Part of this group are joystick, 'chinese-head' and any direction-commanding buttons, as one usually finds on the computer keyboard, right beside the alphanumeric section.

The wwp-input-devices translate a commanded deflection of the device (direction and distance) in speed and direction of the motion of the GIS. All of these devices give no tactile feed-back to the user. Therefore, precision is low and graphic feed-back is vital for operation.

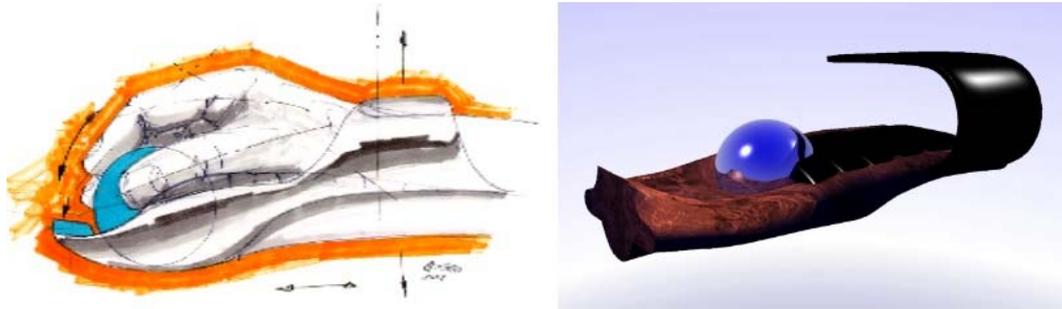


Figure 17: Design study of a new FELIX 3D input device

Regarding current 3D applications, like 3D CAD or virtual reality, there already exist various three-dimensional tracking devices. They come in five basic types according to the techniques employed in measuring translation and/or rotation: electromagnetic, optical, acoustic, inertial and mechanical. Many of these technologies suffer from different problems (e. g. interference with external signal sources, latency, low update rate, inaccuracy, fixed emitters on the tracked item, sensitivity to temperature and pressure changes, error accumulation due to inherent drift, high cost) which make them inappropriate for an application in our volumetric display device. At present the mechanical approach is most likely to satisfy our specific needs.

A mechanical tracker is similar to a robot arm and consists of a jointed structure with rigid links, a supporting base, and an "active end" which is attached to the body part being tracked. Typically simple potentiometers or optical encoders are used to measure the rotation of a joint between rigid linkages. Given the angle of each joint and length of the rods it is a simple matter of geometry to calculate the position of the tracked object. Another type of mechanical tracking is to measure force exerted on a measuring device such as a strain gauge. Typically this technique is used in force-sensing joysticks. Both types of trackers are fast, accurate, and of low cost.<sup>11</sup> For these reasons we chose the concept of a mechanical input device for our display.

The following section introduces current results of our initial design study which we want to verify and test in a first prototype configuration. Apart from that R. Balakrishnan et. al. from AliasWavefront explored various solutions to interaction styles for 3D volumetric displays.<sup>3</sup>

#### 4.2 Felix 3D Input Device

The FELIX-Input-Device (FID) is to operate in three dimensions and six degrees of freedom. Its design should give a maximum of tactile feed-back and allow fast operation in games as well as high-precision input for CAD-applications. Therefore, it is designed to have correct, intuitive translation of commands (wwp-principle). The FID works on a platform, mechanically connected to the display's mounting and connected to the users arm-wrist. It can be moved in circular direction around FELIX, to facilitate optimal point-of-view choice for any user (Figure 18).

If activated, sensors track the expansion or contraction of the mechanical connection as well as the total angular shift. A processor deduces the resulting change in position for all three dimensions and translates the command for the GIS. It should be stressed that a 'forward'-command is always related to the center of the display. This is the only intuitively perceivable method for any user.

Having covered three lateral degrees of freedom, rotation in three dimensions is to follow. Again we use the wwp-principle by combining the platform with a trackball (Figure 17). But now rotation is translated as rotation and not as distance. Obviously, the combination of these two elements follows the physical requirements, mentioned above.

The platform must be well-balanced and have a finely tuned friction, to give force-feed-back to the user. Furthermore, a simple filtering-mechanism must be employed to adjust acceleration-factors (as with the mouse) to allow high-precision

working. We plan to place a number of easy-to-reach buttons on the platform to trigger a command or enable the user to short-cut complex command inputs. These buttons have to be customized in number and shape to the aspired operation.

Parallel to the described platform approach we investigate a 3D input device based on a 3-DOF strain gauge (some kind of joystick with an additional degree of freedom in vertical direction) combined with a trackball element. This variant facilitates part of the mechanical setup.



Figure 18: Vision of the FELIX 3D Display as a volumetric play console

Thus the design of our FELIX-3D-Input-Device would offer a maximum of precision with a maximum of efficiency and still directly addresses the user's intuitive habits and perception. It is therefore an appropriate man-machine-interface for engineering tasks as it is for entertainment applications.

## 5. APPLICATIONS

Spatial visualization of data can simplify or accelerate the working process. If cooperation between viewers is required, volumetric displays have significant advantages compared to common stereoscopic technologies (like *virtual reality*). First, the image they present is visible from a wide range of viewpoints, even permitting viewers to walk all around the display. Multiple users can communicate face-to-face and cooperate in a natural way, because no head gear has to be worn. Each user chooses his own viewpoint independently and has an individual view of the displayed data.

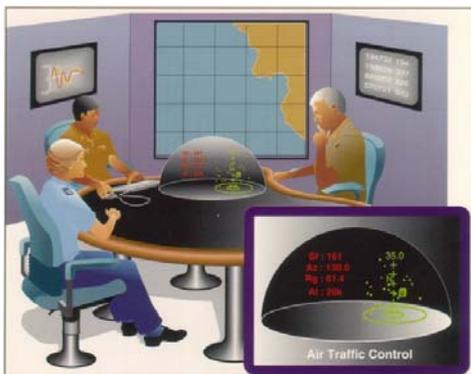


Figure 19: Volumetric display for air traffic control (NRaD)<sup>30</sup>

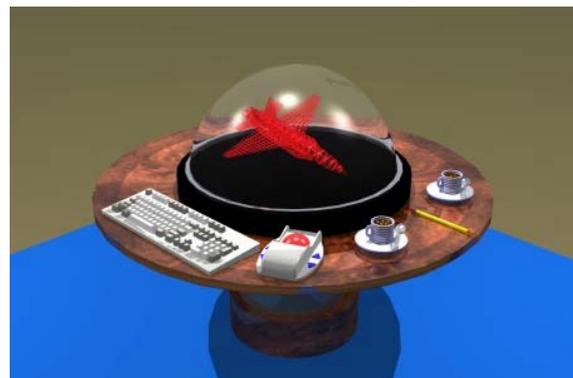


Figure 20: Design study of a FELIX 3D CAD display

In volumetric displays, as described before, the portrayed objects appear transparent, since the light emitted by voxels cannot be hidden from the viewer by foreground voxels. Practical applications seem to be limited to fields where the objects of interest are easily iconized or represented by wireframe models.

An example for an application that would benefit greatly from a true 3D representation is air traffic control. On a flat radar display a three-dimensional space cannot be shown satisfactorily. The missing third dimension, in this case the flight altitude, must be indicated by figures. As a consequence a controller has to constantly observe all aircraft on the radar screen to form a mental image of the actual airspace situation. After an interruption, his mental image is disturbed and he needs some time for readjustment. A true 3D volume display should be designed to complement state-of-the-art 2D radar displays for an improved performance needed on safety-critical observation tasks (Figure 19).

For displaying three-dimensional graphics on a 2D display occlusion and shadowing are the most important depth cues. A volumetric display would help to interpret wire-frame structures because the depth cues accommodation, convergence, stereoscopic vision and the laws of perspective are satisfied. Thus a volumetric display is a useful complement to common CAD tools reducing prototyping costs (Figure 20).

This following list summarizes further examples for possible applications:

- Scientific visualization:  
Projection of multi-dimensional, complex data structures and graphs.
- Entertainment:  
Demonstration of FELIX as an interactive 3D play-console (Figure 18)
- Computer Aided Design (CAD):  
Projection of a 3D wireframe graphic of an aircraft structure (Figure 20).
- Chemistry/physics/pharmacy:  
Visualization of molecular structures (Figure 21).
- Medical Imaging:  
Display of a human skeleton in three dimensions (Figure 22).
- Air Traffic Control:  
3D visualization of a typical air traffic scenario close to an airport (Figure 19).
- Interactive 3D internet communication tool:  
Working teams from different places all over the world can interactively discuss and manipulate a spatial design.



Figure 21: Visualization of molecular structures: macro molecule



Figure 22: Display of a human skeleton in three dimensions

## 6. CONCLUSIONS

In this paper we have introduced our FELIX 3D Display as an interactive tool for volumetric imaging. This development refers to the well-known swept volume techniques. Spatial images are drawn by a computer controlled laser beam on a spinning screen under a transparent acrylic dome. The effect is “a bit like enclosing a model ship inside a bottle, which a person can view from any side” (R. Batchko). The difference is that with our display a person can see

through the image because the object surfaces are transparent. With the ability to simultaneously observe internal structures of an object, the lack of occlusion may become an advantage (e.g. for medical applications). For solid bodies an alternative display technique is required.

In order to provide an appropriate man-machine-interface for interactivity purposes we have presented a design study for a new 3D input device. We chose the concept of a mechanical approach because it offers a maximum of precision and it directly addresses the user's intuitive habits and perception.

The projected images within FELIX provide a fascinating, aesthetic impression through its inherent, unique three-dimensional appearance from nearly all around the display. Thus, in a time where many implementations aim at sophisticated photo-realism resolutions, even a 3D display as described with a comparatively low resolution (due to the added third dimension) will find its applications (e.g. entertainment, air traffic control, scientific visualization).

Through the availability of novel micromachined components like Digital Micromirror Devices (DMD<sup>TM</sup>), state-of-the-art laser TV projection systems, and spatial light modulators new possibilities evolve to significantly increase the performance of the suggested 3D display configuration. These techniques provide parallel voxel processing capabilities which could significantly improve the performance of our volumetric display system.

The data rates required by high resolution true volumetric graphics may become a challenge. But parallel architectures with multiple processors and image-compression techniques could reduce the loads. By its modular design our FELIX 3D Display represents a powerful, flexible development tool to benefit from the rapid technology advances. Innovative projection techniques can easily be implemented for further design steps towards the HOLODECK.

## ACKNOWLEDGMENTS

We thank Prof. Dr. Dietmar Müller, Dr. Detlef Billep, Ralf Seidel, Heiko Kiessling (Faculty of Electrical Engineering and Information Technology at the Chemnitz University of Technology), Prof. Dr. Ernst Heumann and Dr. Klaus Petermann (Institute for Laser Physics at the University of Hamburg) for their support, cooperation, and for providing hardware needed for our research and the development of the FELIX 3D display. We thank also Christhard Deter from LDT (Gera, Germany) for providing us a laser projection unit.

Digital Micromirror Device, DMD, Digital Light Processing, DLP are trademarks of Texas Instruments Incorporated.

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