THREE DIMENSIONAL OPTAR

N. S. KAPANY
OPTICS TECHNOLOGY, INC.
PALO ALTO, CALIFORNIA

ABSTRACT A three-dimensional data acquisition and display system using fiber optics is described. The system consists of a range-gated pulsed laser illumination source and a direct view image intensifier or remote view camera tube sensor. Such sensors have been effective in locating, ranging, and observing targets which may be located behind a scattering medium such as clutter, haze, or camouflage. The ability to control the viewing time of the sensor allows the back-scattered light to be gated out, thereby providing enhanced detection and recognition capability. The three-dimensional information is obtained by range-gating the different z-planes in time.

The display system consists of fiber optics slugs of varying thicknesses, and each frame in the object plane is projected on a different fiber optics slug. This entire data acquisition and display occurs at a speed faster than the flicker frequency of the eye, thus penetrating a real-time, three-dimensional view of the object.

A prototype of the three-dimensional display system is explained and various alternate approaches for data acquisition, data recording, and data display is described.

I. INTRODUCTION

The question of visionic aids to target acquisition and designation have foundered on the physical and psychological problem of detection and recognition probability. The visual recognition and classification capability suffers for a variety of reasons. Atmospheric noise, environmental impediments, and deliberate camouflage as well as psychophysical variables have combined to produce a limit to the efficiency of most classical approaches, such as increase in light gathering ability or total magnification. As a result, emphasis has lately been placed on far more sophisticated systems incorporating such techniques as chromatic frequency shifts and spatial filtering, which modify the image presented to the observer.

The interposition of a monocular or short-base binocular instrumental aid between observer and target, whatever its advantages may be in the enhancement of some parameters, automatically prohibits use of one of the traditionally most valuable of all human ocular abilities, namely, stereoscopic vision. Under conditions of stress and requiring critical judgment, this ocular disorientation can result in a near total inability to recognize the most familiar of objects and the art of camouflage has long taken advantage of this fact. The classic dazzle painting of ships, the bamboo gun barrel mounted on a bush, the plywood silhouette tank are unsophisticated, but highly effective employments of the disorientation caused by the inability to resolve three dimensional objects at a distance.

It is apparent that an optical system is needed that can retain all the required quality of an image scene without at the same time integrating the original 3-D image information down onto a single plane, thereby frequently throwing away useful information.

This reduces to the problem of collecting and preserving the depth information contained in a scene, while the image is being processed to optimize its quality; and then reconstructing the scene with enhanced image quality so as to deliver the depth information to the observer in real time. Physically, this imagery and subsequent presentation of depth information to an observer is just a question of finding a device or technique that will subjectively image a large distant volume of space into a small proximal volume for direct viewing, storage or processing.

SYSTEM CONCEPT

The use of range-gating systems which utilize pulsed lasers and either direct view (image intensifiers) or remote view (camera tubes) sensors have been shown to be highly effective for locating, ranging and observing targets which may be located behind a scattering medium, such as clutter, haze of camouflage. The ability to control the viewing time of the sensor allows the backscattered light from the near field to be eliminated (gated out), thereby providing enhanced detection and recognition capability.

Our technique for acquisition and display of 3-D information is based on a concept that an effective volume (x, y, z) can be constructed from a stack of (N) x-y planes, or frames, which are generated by a refined range-gated system. Each plane carries the information associated with its own slice of the depth (z) axis in target space (Figure 1). The projection on a screen of frame III (x_3, y_3, $z_1 + 2\Delta z$) alone is illustrated in Figure 2. Now a method is used for sequentially retrieving images of slices $[x'_n, y'_n, z'_1 + (n-1)\Delta z]$ (where n is the frame number) as a single planar projection, demagnifying them for increasing n and displaying them in a three-dimensional image space $[x'_n, y'_n, z'_1 + (n-1)\Delta z']$.

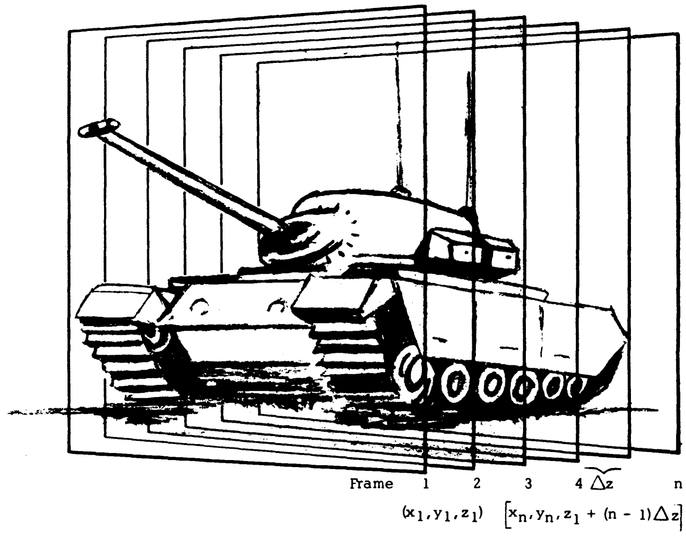


Figure 1. Image Dissection on the z-Axis

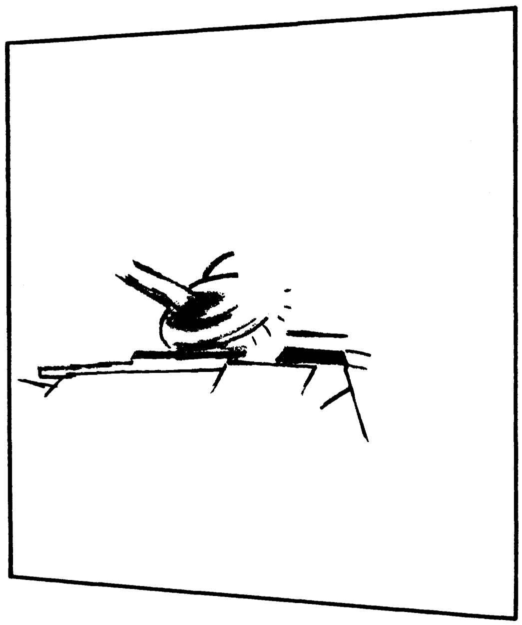
Thus, the observer would see a raster of frames in depth presented sequentially at a frequency greater than the flicker frequency of the human eye. He would than be able to recognize, in three dimensions, any object whose projection was at least partially present in more than one frame, e.g., in Figure 1 it is clear that the gun would be present in frames 1 and 2 as well as frame 3, thus the observer would see the gun standing out toward him. Basically, the technique reduces to two operations:

a. Interrogation of the object space in such a way as to sequentially obtain multiple planar images at differing ranges.

b. Sequential reproduction of these planar images as frames of a "raster-in-depth" in a volume of space that can be directly viewed by the observer.

Such a technique is readily implemented by interfacing a sequentially range-gated optical system with the 3-D display system to be described.

We note that the smallest object that the observer will be able to recognize as having depth will be one that occupies a large fraction of the frame



3

Figure 2. Detail of Frame 3, Figure 1.

depth, which is determined by the 'depth resolution' of the optical range-gating system. We also note that since the reconstruction can be done in real time, the observer can have the object displayed to him as it is then and there, and any changes in the actual object seen will be exactly reflected in real-time changes in the scene that is observed.

The volume of space which the observer is visually examining as the reconstructed image can be either real or virtual. Techniques for accomplishing both real and virtual reconstruction of the 3-D volume have been developed.

We will describe two systems for presenting the laser illuminated field in three dimensions. Such a system would offer many advantages for both daytime and low light level viewing and would be useful for many applications, such as reconnaissance, surveillance, close formation flying, station keeping, night driving, target ranging and identification, etc.

II. TECHNICAL DISCUSSION

For typical objects of interest, ranges extend from less than a hundred meters out to several kilometers, and target depths from 15 to 150 meters. Reasonable range resolution for displaying such targets requires optical range-gating of the order of 5 to 10 nanoseconds. Also, the number of frames required to produce a high depth resolution, flicker-free display increases the repetition rate requirements of the range gating system. Electronic controls can allow for varying the range and depth of the target volume, and also, it is possible to alter the perspective of the target.

Let us discuss some of the parameters affecting the design of a 3-D viewing system incorporating range-gated lasers.

a. Laser Range Gating

A typical laser range gating system is represented in Figure 3. The laser emits a short light pulse of duration Δt. The laser beam is shaped by the output optics to produce a light pulse subtending a solid angle Ω in the far field, which is capable of illuminating an area larger than the target in the object volume. As an object reflects and scatters light incident upon it, some will fall within the receiver acceptance angle. The receiving optics, in turn, image the object plane onto the photocathode of a gated image tube, and the viewer optics permit the observer to see the range-gated image.

b. Description of 3-D Display System Techniques

The laser range-gated system provides a means of optically slicing the target into a number of frames in the

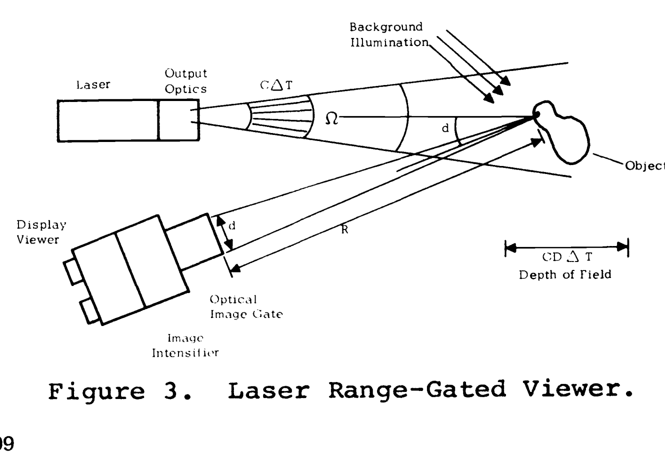


Figure 3. Laser Range-Gated Viewer.

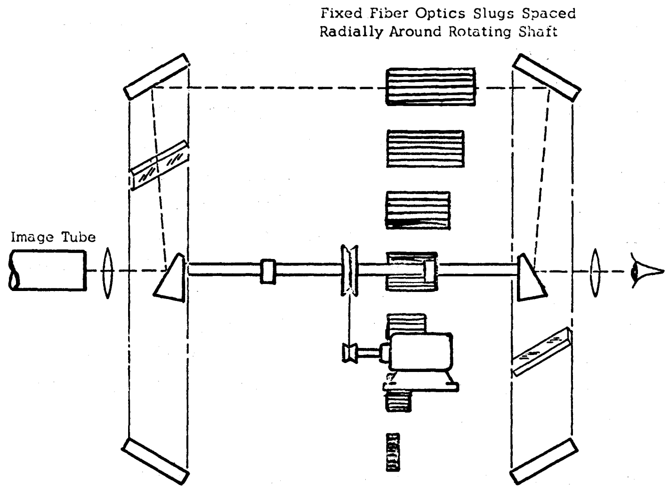


Figure 4. Optomechanical Viewing System Utilizing Fixed Fiber Optics Slugs and Rotating Shaft.

z-direction (Figure 1). By using each output pulse from the laser for the illumination of a single slice, sequentially changing the range gate delay between the pulse output and the turn on of the image tube permits the successive imaging of the various frames at the output face of the tube.

A real 3-D display can then be synthesized from the consecutively gated image frames at the image intensifier using several simple techniques. These various display methods are based on displacing the real or virtual image of the image intensifier output in phase with the raster generated in the real field using the range-gated transmitter and receiver.

One such configuration is shown in Figure 4 where a set of rotating mirrors are confined to a simple shaft, and fiber optics slugs of different lengths are distributed on a circumference around the shaft with 45° mirrors relaying the image between the mirror fixed to the common rotating shaft and the individual fiber optics slugs. This system can be very compact and has considerable versatility with respect to the fiber optics slug configuration.

In order to maintain a true perspective under conditions of overall field magnification, it is essential in some instances that each of the frames should have differing magnifications. This can be readily achieved in the fiber optics systems by constructing the individual elements from fused fiber optics cones, so that the fiber optics component itself can be made to both introduce arbitrary magnification and the required image displacement.

These systems generate a real three-dimensional display in which those targets that are illuminated in the original field are reconstructed in their correct location in the three-dimensional display. However, targets that are masked from direct illumination in the laser pulses by obstacles in the forward field will obviously not be illuminated and hence will not appear in the reconstructed field. In particular, the sides of targets may be partially masked by the frontal area of the targets, so that the three-dimensional display will look unreal when viewed at large angles. However, when viewed within 10 to 20° or so of the optical axis of the system, the reconstructed image will be an accurate real display of the physical field so long as the entire target receives illumination.

c. A Stereoscopic Electronic System

An alternative approach to generating a 3-D display based on stereoscopic viewing offers more flexibility, but does not generate a real three-dimensional reconstructed field. In this

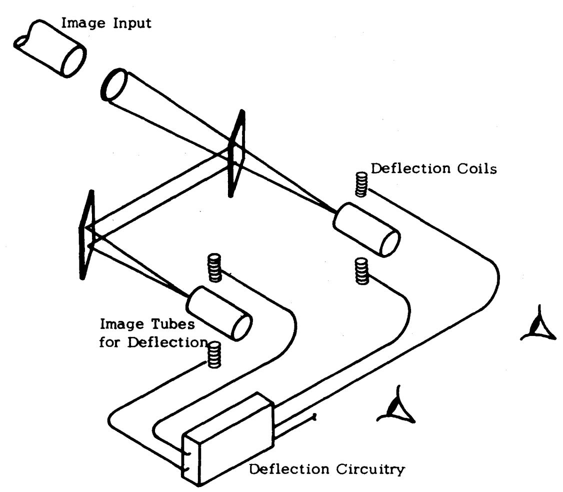


Figure 5. Electronic Stereoscopic Viewing System.

system, the instantaneous images from either a single or double image tube are relayed to the observer via a binocular viewing system as shown in Figure 5. The image magnification is varied using a zoom image tube, and the images are synchronously deflected with the range gate raster generator to display a stereoscopic picture to the observer. The correct size, location, and angular subtence can be presented to the observer's eyes, and this information will be interpreted by the brain as a 3-D image. However, parallax resulting from the motion of the observer's head will not be as evident as in the previously described system. The required displacement would normally be very small and, in fact, satisfactory displays may be constructed without requiring magnification, but merely a variation in the deflection. This all-electronic display system has greater flexibility though requiring the utilization of more advanced technologies.

d. 3-D Demonstrator

Figures 6 and 7 show the optomechanical 3-D display system using a rotating wheel and fiber optics slugs of varying lengths. To simulate the projection of a raster-in-depth on the fiber optics elements, individual photographic negatives of a series of image planes through a test target can be fastened to the back of the fiber slugs. Thus, when the wheel is rotated at a high angular velocity and illuminated with a synchronous strobe light, a 3-D image is constructed. Figure 8 shows three drawings of the images at three differ-

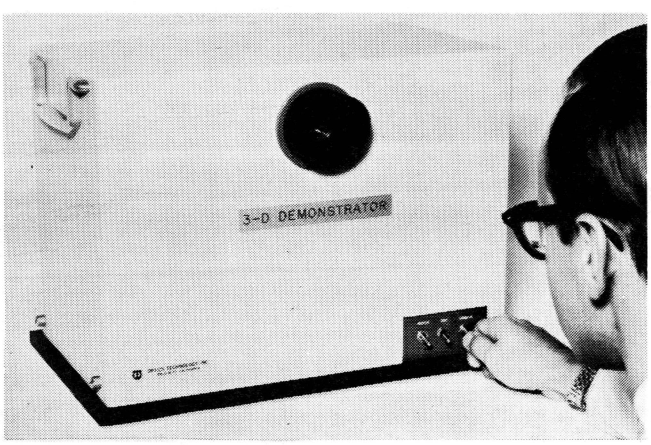


Figure 6. 3-D Demonstrator

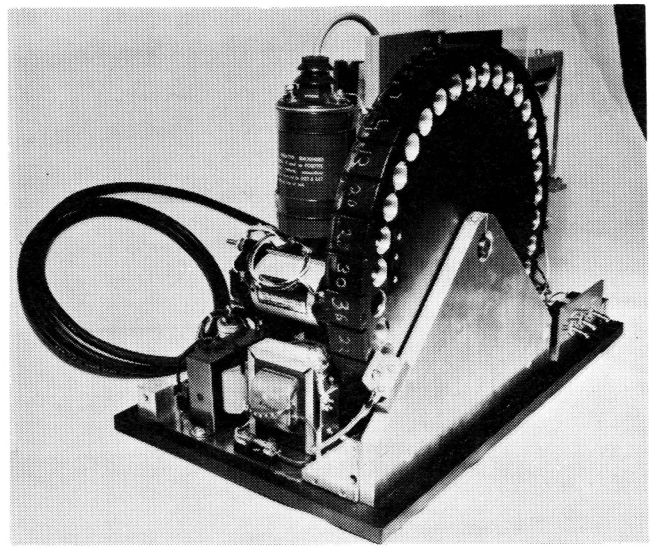


Figure 7. Internal Assembly of 3-D Demonstrator

ent angles to illustrate the true 3-D shape of the image achieveable. The image quality and information content in the actual demonstrator has been shown to be far higher than could be captured on conventional photographs.

The applications of the 3-D demonstrator for displaying information stored or synthesized through a computer or other forms of data storage and display devices also hold considerable promise.

III. SUMMARY

Visual identification and psychophysical orientation through association with an electronically processed image is greatly facilitated by the presentation of the image in three dimensions. This is partially the result of the increased information carrying capacity of a 3-D image, but largely arises from subjective associations with a more "true-to-life" image. As a result, 3-D displays are far superior to 2-D displays of equivalent information carrying capacity for the presentation of visual data.

We have outlined a technique which has been demonstrated in the laboratory, to produce satisfactory 3-D images. A pulsed laser illuminated field of view is dissected into a number of successive image planes or frames using "sequential range-gating" which are then dis-

3/4 VIEW TOP VIEW SIDE VIEW

Figure 8. Two-Dimensional Drawings of 3-D Demonstrator Images.

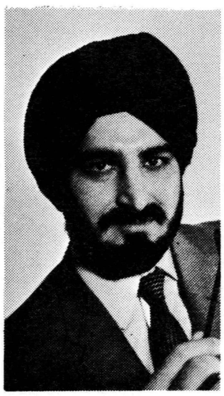
played at different z-planes synchronously with the laser pulse-gating operation. An optomechanical viewing system is described which makes use of the ability of fused fiber optics plates to faithfully transfer an image projected on one face of the plate to the opposing face regardless of the length of fiber optics. Sequentially changing the fiber plates so that the projected images appear at different planes, depending on the thickness of the respective plates, produces a 3-D reconstructed image of the illuminated field of view when the framing rate is fast enough to result in a flicker-free image. Other optomechanical means of accomplishing this are also discussed.

A second viewer is described which produces a virtual 3-D image by the creation of a binocular stereoscopic pair from the successive image slices projected on the photocathode of an appropriately designed electron image tube assembly. A modification of this technique can permit the generation of a stereoscopic pair in real time from a single output laser pulse illumination of the target.

Either technique has the capability of artificially changing the apparent position of the observer through manipulation of the magnification (both in the x-y plane and the z-direction), binocular parallax, and image perspective in such a manner that subjective association with the apparent location of the observer relative to the target can be maintained. Briefly, the observer can be made to believe that he is much closer to the target than the actual observation point. The advantages of this system of display over any 2-D display system are obvious.

IV. ACKNOWLEDGEMENTS

I am particularly indebted to Paul Palanos and Dr. Fred Unterleitner for their most valuable contributions and assistance.



NARINDER S. KAPANY is President, Chief Executive Officer and Director of Research of Optics Technology. Recently he has been concerned with research in optical switching, radiography, x-ray image intensification and lasers. Dr. Kapany has originated new instrumentation techniques for sine wave image analysis, spot diagram image synthesis, refractometric analysis and dimensional measurement by electronic interferometry. He developed the currently used techniques for the fabrication and use of optical fibers, and has written over 50 papers and patent applications on fiber optics alone. Dr. Kapany graduated from Agra University in India, performed graduate work in optics at the Imperial College of Science and Technology, London, and received his Ph.D. from the University of London in 1954. He was awarded a Fellowship in Optics and later a Royal Society Scholarship while attending the Imperial College.