3D IMAGING IN THE STUDIO (AND ELSEWHERE...)

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ABSTRACT

At 3DV Systems Ltd. we developed and built a true 3D video camera (Zcam), capable of producing RGB and D signals where D stands for distance or depth to each pixel.
The new RGBD camera makes it possible to do away with color based background substitution known as chroma-key as well as creating a whole gallery of new effects and applications such as multilayer foreground as well as background substitutions and manipulations.
The new multilayerd modality makes possible the production of mixed reality real time video as well as post- production manipulation of recorded video.
The new RGBD camera is scannerless and uses low power laser illumination to create the D channel. Prototypes have been in use for more than 2 years and, are capable of sub-centimeter depth resolution at any desired distance up to 10 m. on the present model. Additional potential applications as well as low cost versions are currently being explored.

1.INTRODUCTION

The art of creating video films by combining images taken in the studio and images created by graphic artists on a computer or by hand or by an additional camera is an important part of video production.
In many applications chroma-key background subtraction is used in the studio as a mean of replacing the background by any desired image both artificial and real. The method is extensively documented in the literature some examples are: [1], [2], [3].
The chroma-key technique has the advantages of being simple to comprehend and yield very good quality images that made it popular it can achieve image implantation to a precision level of a few pixels.
Beside the advantages, the method has some drawbacks listed next that can be eliminated by using our new camera as will be shown.

Single layer interchange
Only layers in the back can be changed
Requires blue background color (blue usually) screen
Requires studio environment
Actors cannot use blue dresses or blue objects

If however, the video producer wishes to insert into the field of view layers and objects located at any desired distances from the camera the c-k method is incapable of doing it.
This limitation is even further enhanced if one wishes to keep the existing background in addition to the implanted layers.
3DV has developed and patented a robust method for performing multilayerd implantation and replacement has to be based on complete data of the field of view (FOV) that is the RGB data as well as the D distance data for each pixel in the FOV.
The new camera known under its trademark name as Zcam is hence a true 3D video camera.
The concept behind the camera is very versatile and may be applied to many fields, some of which will be discussed later.
The two figurers (1 & 2) present schematically a typical scenario of replacing and inserting layers according to their relative range position vis-‡-vis the camera.

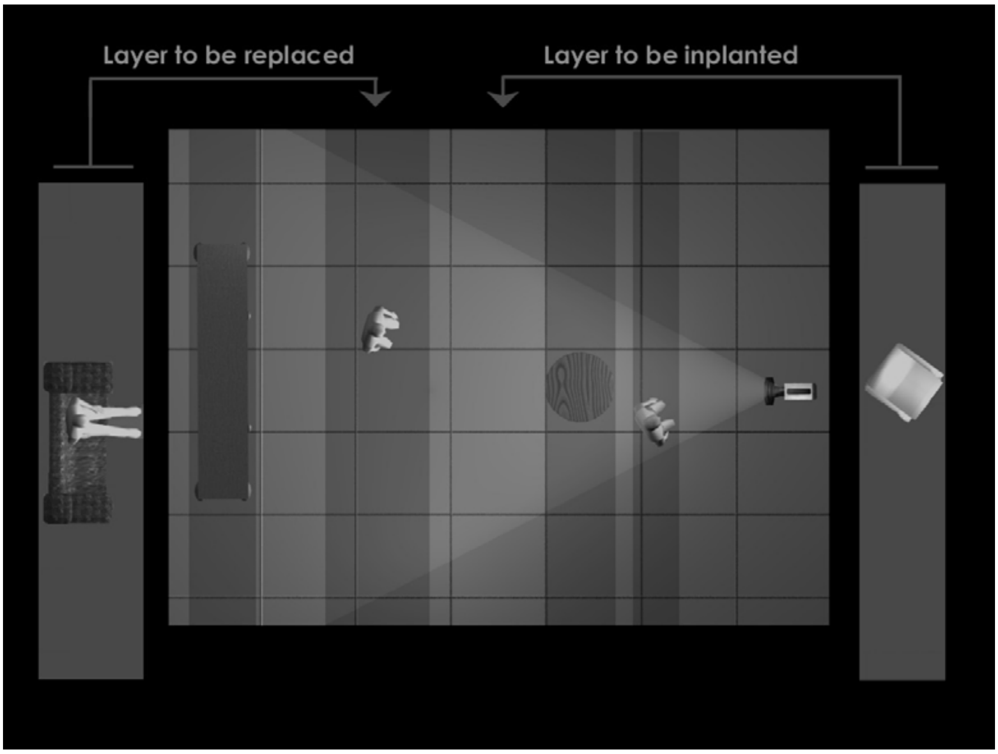


Fig. 1: The original scene to be modified

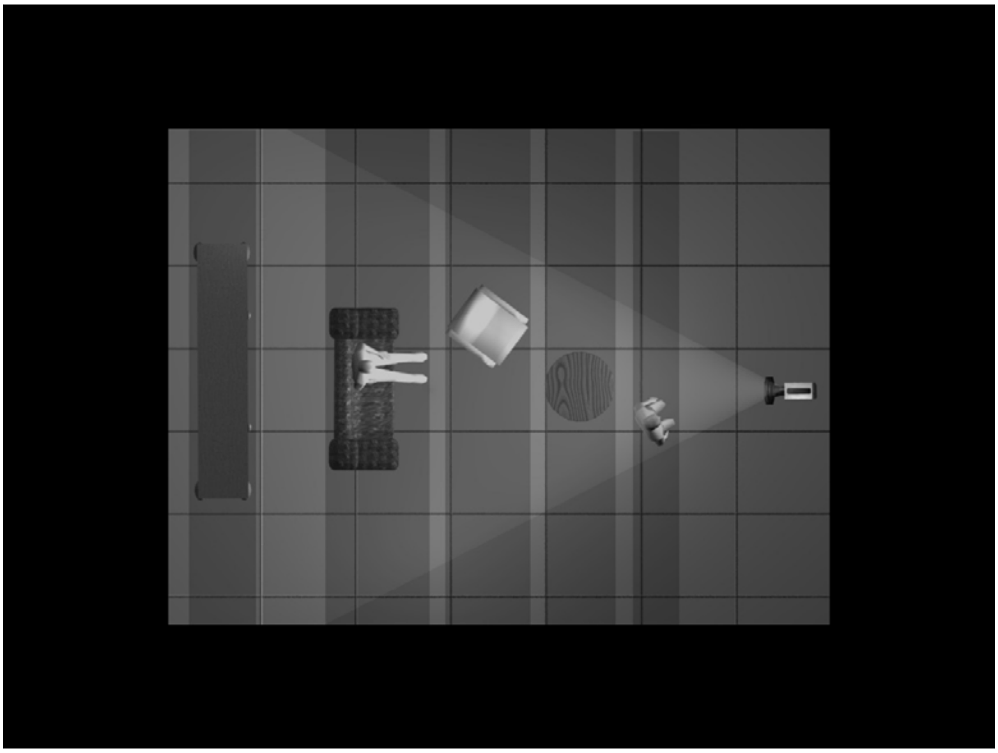


Fig. 2: The scene after the modification

2. THE CONCEPTS BEHIND THE CAMERA

The basic tool used for the placement and replacement of layers in the FOV without resorting to c-k is a special camera that delivers for each pixel in the FOV in addition to RGB an additional parameter D indicating distance.
In a sense this is a camera capable of generating 3 dimensional images of the FOV or to be more precise 21/2 dimensions when looking from a single vantage point. The unique camera is capable of doing so at video rate and is compatible with all existing standards and formats.
The concept of operation is based on generating a "light wall" having a proper width moving along the FOV. The said ì light wall ì can be generated for example as a square laser pulse of short duration having a field of illumination (FOI) equal to the FOV (fig. 3). As the light wall hits the objects in the fov it is reflected back towards the camera carrying an imprint of the objects. The imprint contains all the information required for the reconstruction of the depth map.

Fig. 3: ì light wallî moving along the FOV.

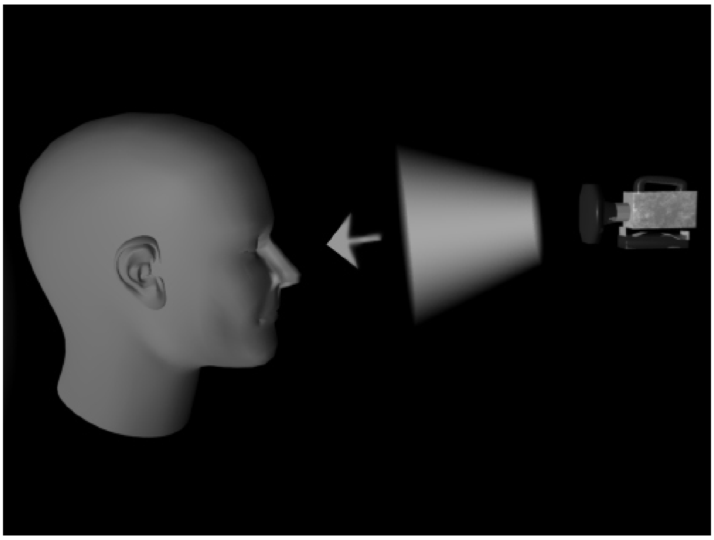
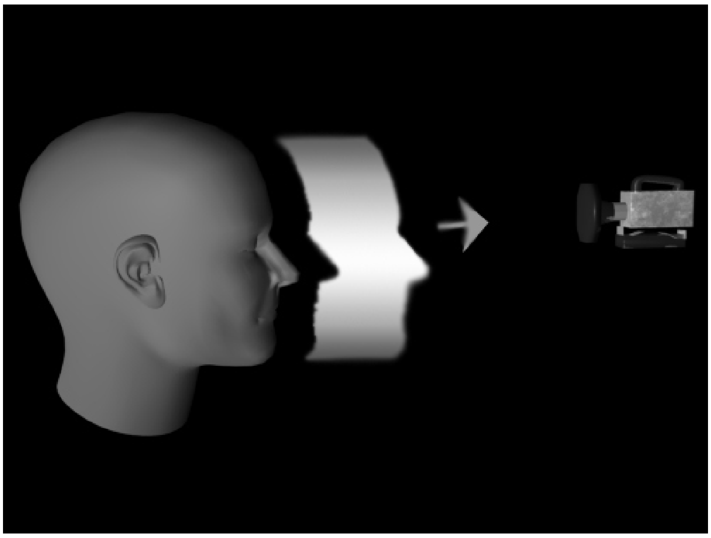


Fig. 4: imprinted light wall returning to camera.



The 3D information can now be extracted from the reflected deformed "wall" by deploying a fast image shutter in front of the ccd chip and blocking the incoming light as shown in fig. 5.

Fig. 5: Truncated "light wall"- front cut

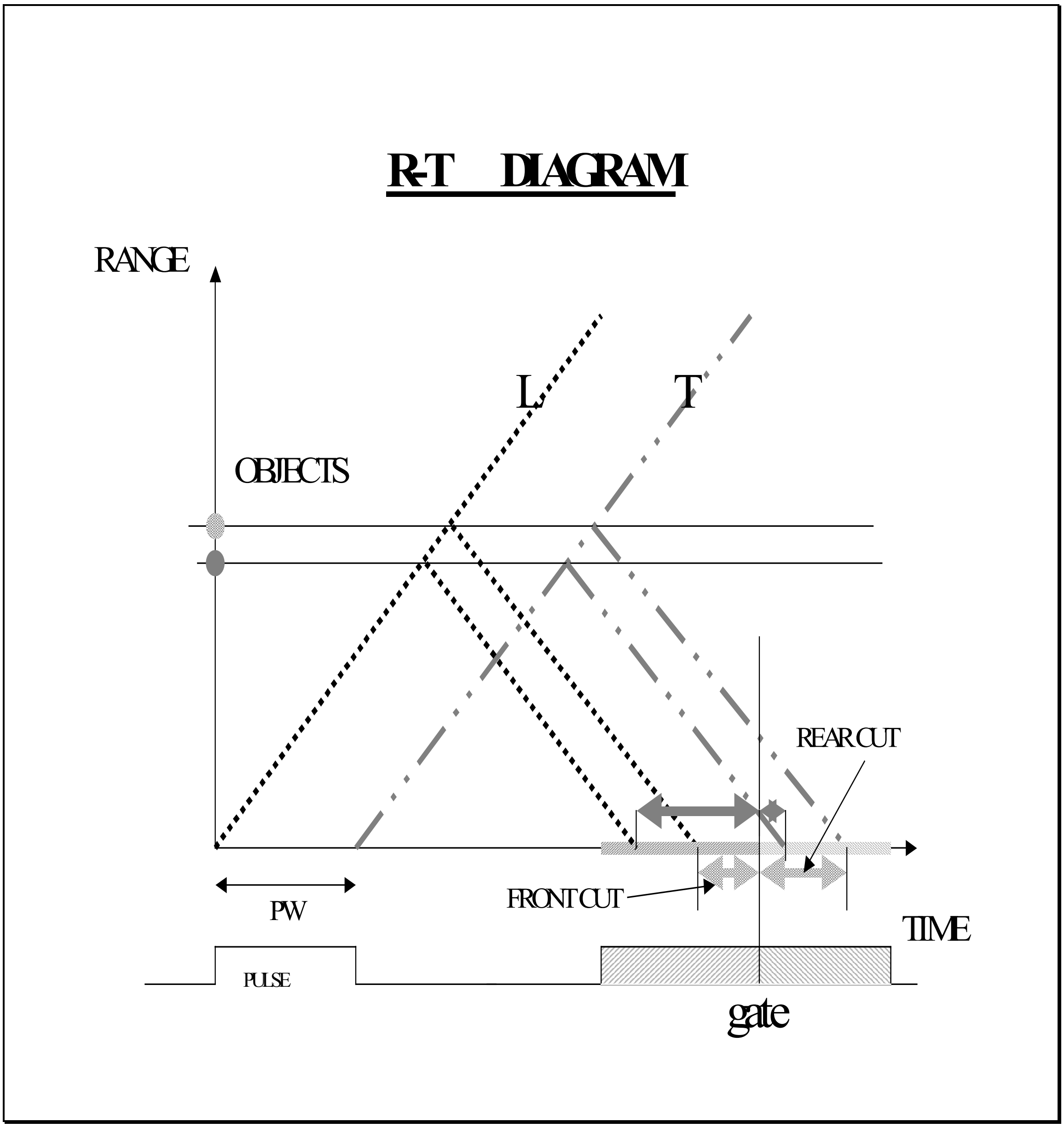
The collected light at each of the pixels is inversely proportional to depth of the specific pixel. As an alternative it is possible to retain the rear
section of the reflected wall (fig. 6) and thus get the ìnegativeî of the depth.
Since reflecting objects in the FOV may have any reflectivity coefficient there exist a need to compensate this effect and hence a normalization procedure is introduced.

Fig. 6 rear portion of the reflected light wall (rear cut).

The normalized depth of pixel (i,j) can be calculated by simply dividing the front portion pixel intensity by the corresponding portion of the total intensity:

$$\mathbf{R}(i, j) = \mathbf{I}(i,j)\ \text{front} / \mathbf{I}(i,j)\ \text{total}$$

Hence resulting reflectivity normalization procedure, which completes the capture of the depth, map that comes out as a conventional black/white image.
Fig. 9, which comes next, is a very illustrative graphical representation of the kinematics of the light ray corresponding to a single pixel in the image much like the diagrams used for explaining the special theory of relativity.



The camera belongs to a broader group of sensors known as scanner less LIDAR i.e. laser radar having no mechanical scanner an early example is Scott [4] and his followers at Sandia.

3. SOME TECHNOLOGICAL ASPECTS:

Operating the camera is based on the following two technologies

1. Fast switching of the illumination source to form the ì light wallî .
2. Fast gating of the reflected image entering the camera.

A cluster of IR laser diodes and corresponding optics is used to generate a homogenously illuminated the FOI. The diodes are switched on/ off with rise/fall time shorter then 1 nsec. Although fast drivers and switchers are commercially available non of the existing models was suitable for our extreme application hence, super fast driver electronics had to be designed to comply with the fast response, the small space and yet maintain high efficiency.
As is well known in the art (radar systems), the detection of the reflected pulse has to be synchronous with the switched illuminator, for that purpose, a special fast driver has been designed having again rise/fall time shorter then 1 nsec.

The reflected light is not collimated since large FOV is required which excludes the use of Kerr or Pockels cells for the purpose of reflected image fast switching. Our present camera incorporates a gated intensifier as means of getting the fast image switching this later device is commonly used for that purpose by other designers we had however to modify the conventional design to achieve the required performance.
Since the beginning of our design, efforts were made to devise some new way and devices for fast switching of the un-collimated image. We now have two ways to reach the goal both are solid-state devices each suitable for a different version of our 3D camera. The new devices will in the future replace the image intensifier in our designs.
As previously explained the 3D camera has to simultaneously capture the range image as well as the RGB image under studio environment where the use of zoom is a must, to get the two images at perfect overlap the same shooting lens has to be used for both images thus indicating a sophisticated optical design and spectral separation. Fig. 7 presents the block diagram design of the cam

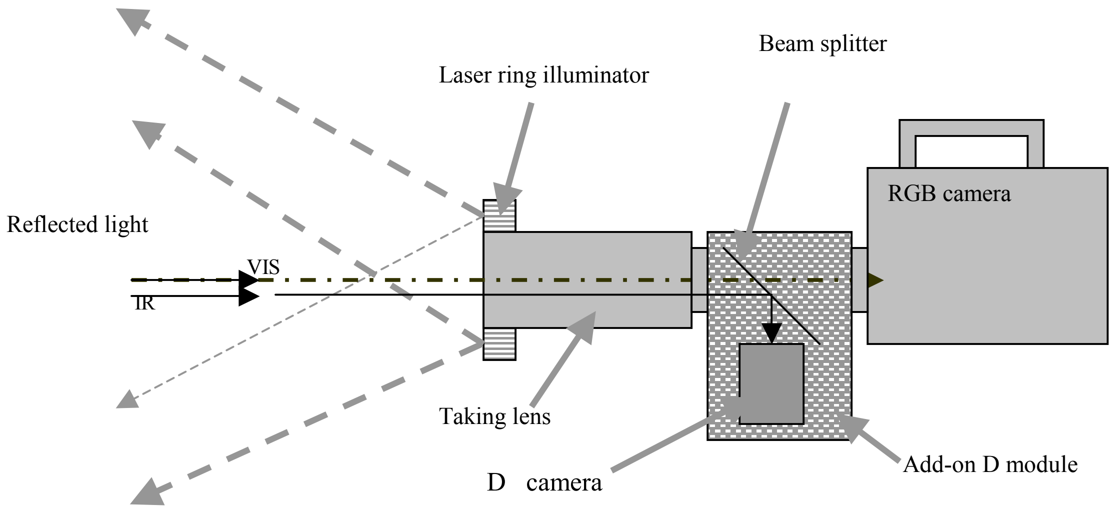


Fig. 7: Main Building blocks of 3DVís Zcam

As can be seen the laser ìlight wallî emerges from illuminator to form the FOI, reflected light forming the FOV is gathered by the taking lens which can be zoomed if so desired.
At the D module the incoming light is split the through visible portion goes to the RGB studio camera while the IR portion is deflected towards the D camera, which delivers the depth map.
As a general rule we try to keep FOI = FOV to minimize light loses and keep the illumination at eye safe levels.
A photograph of the camera is shown in fig. 8.

Fig. 8: 3DVís Zcam II

Fig. 9

4. ZCAM II SPECíS (AUG. 2000):

The current updated parameters are gathered in the next table and one should keep in mind that many environmental and operational parameters affect the figures hence they should be considered as typical.

Range:	1 to 10 m.
Range resolution:	0.5 cm
	(When operating inside a small range window)
FOV:	10 to 40 deg.
IR wavelength:	800 micron

Figure 9 shows the 4 steps in creating a virtual background
The original image (a) taken by the color RGB camera
Depth image (b) created with the depth camera (gray level inversely proportional to range),
Mask (c) similar to the mask obtained by chroma-key
Final manipulated image having a virtual background (d).

5. SUMARRY AND FUTURE WORK:

Zcam, as described, is suitable for a verity of studio applications and indeed the camera has participated in some shows and demonstrated some amazing special effects which up till now were impossible to implement even offline as post- production operation a short video clip will demonstrate a sample of the capabilities of the new camera, additional information may be found on our web site (www.3dvsystems.com).
In the future the Zcam will be modified to an all solid- state device thus opening some new capabilities some of which are:

- Size reduction.
- Integration of the D channel into the RGB camera
- Low cost single chip model
- Increasing the illumination power and reducing the FOI and the FOV correspondingly can extend the operation range of the camera.

In some shows we demonstrated true 3D video taken in real time with the Zcam and screened to the visitors at the show incorporating our special effects capability.

7. REFERENCES:

[1] McCoy, R.F.H. Television images positioning and combining systems U.S. patent #4,393,394 1983.
[2] Shimoda, S. Hayashi, M. and Kantsugu, Y. New chroma-key imaging techniqueÖ . IEEE Trans. On Broadcasting, Vol. 35, No. 4, 1989.
[3] Fukui, K. Hayashi, M. And Yamanouchi, Y. A virtual studio system for TV program production SMPTE Journal, June 1994.
[4] Scott, M. W. Range imaging laser radar US patent# 4,935,616 1990