A Holographic Visualization System: a Sequel

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Abstract. This work reports developments on a system for 3D visualization based on "Holoprojection", a depth coding technique. This system allows visualization using several planes of depth of textured images, such that all depth cues are present under certain limits. The 3D volume can be observed with no auxiliary devices, such as stereo glasses.

Keywords: Holography, 3D Projector, Holographic Screen, 3D Visualization.

1 Introduction

Although it is possible to represent a 3-D object in a 2-D surface, the image thus formed does not have true depth cues. The depth cues that may be represented in a 2-D surface are: linear perspective, shadows, aerial perspective, occlusion, texture gradient, size of image in the retina and temporal parallax [CW93]. Those depth cues make possible a 2.5-D representation and are extensively used in Computer Graphics. However, for a spatial 3-D representation of a scene we need to provide other depth cues, such as binocular disparity and movement parallax. Those depth cues are important in scenes which present complex 3-D data or have unfamiliar objects. This includes scientific visualization, CAD, simulation and telepresence. In a previous work we discussed some of the techniques for displaying volume images [FML97]. A prototype "Holoprojector" is presented in [Dia94]; early developments of a second-generation Holoprojector can be seen in [BM+96]. This work presents the final status of the second generation Holoprojector, whose detailed description can be found in [Ber98].

2 A System for Virtual Holography

We use a technique called *holoprojection* [BM+96] [Dia94], in which a system for holographic visualization is made of a white-light source, a diffraction grating, a holographic screen and a computer that controls the mechanical apparatus and generates the images displayed in three dimensions. The *holographic screen* [Lun93] is a special diffractive lens which receives a white beam of light from a projective lens and diffracts it in different wavelengths, to different directions, This can generate several views, which will encode depth.

The system projects two-dimensional slices which look like a sliced bread, however those slices are textured pictures shown in planes at different depths (see Figure 1).

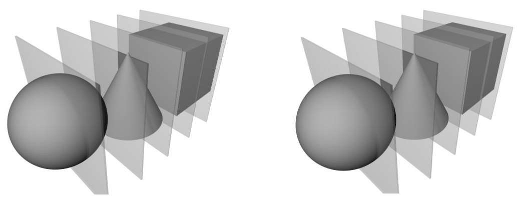

Figure 1: A stereo pair showing the slicing process.

The second-generation Holoprojector can be depicted from Figure 9, later in this article. The slices created by a modified version of a ray tracing program from a three-dimensional scene description are shown one at a time. Each projected slice passes through a diffraction grating for depth encoding and then through a set of lens, so as to be projected over a mirror in movement, which is controlled by the computer in a synchronized way. This mirror puts each projected slice in a transversal position in relation to the holographic screen, thus forming an exhibition volume. The projector is a Sharp XG-400U, which is connected to a standard PC fitted with a suitable graphics card.

3 Problems found during development

By the time previous work on this system was reported [BM+96], good visual results were barred by limitations on the mechanical apparatus in use, as well as by software issues on the PC platform that controlled the apparatus. A visual example of this can be seen in Figure 2.

In order to sustain movement of the reflecting mirror, we ended up taking apart a floppy disk drive to get its head movement assembly. A reduction mechanism was then assembled, using a pulley-belt-pulley arrangement. Control of the step-motor was done by the PC's standard floppy controller using assembly language [BM+96]. A limitation on the mirror movement speed, i.e. on the re-

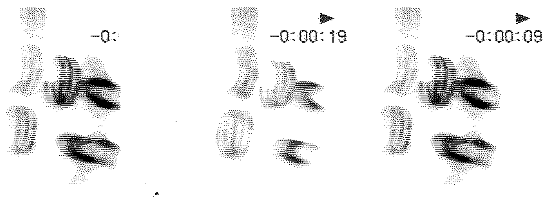

Figure 2: First result obtained with the second-generation Holoprojector.

sulting refresh rate, was caused by the BIOS parameters associated with the floppy controller. Each step could not be faster than 26-27 *ms*. Also, any improvements that could be obtained otherwise were bound by the inertia of the whole apparatus and by the elasticity of the belt, not only in respect to the speed of the movement, but also to its quality.

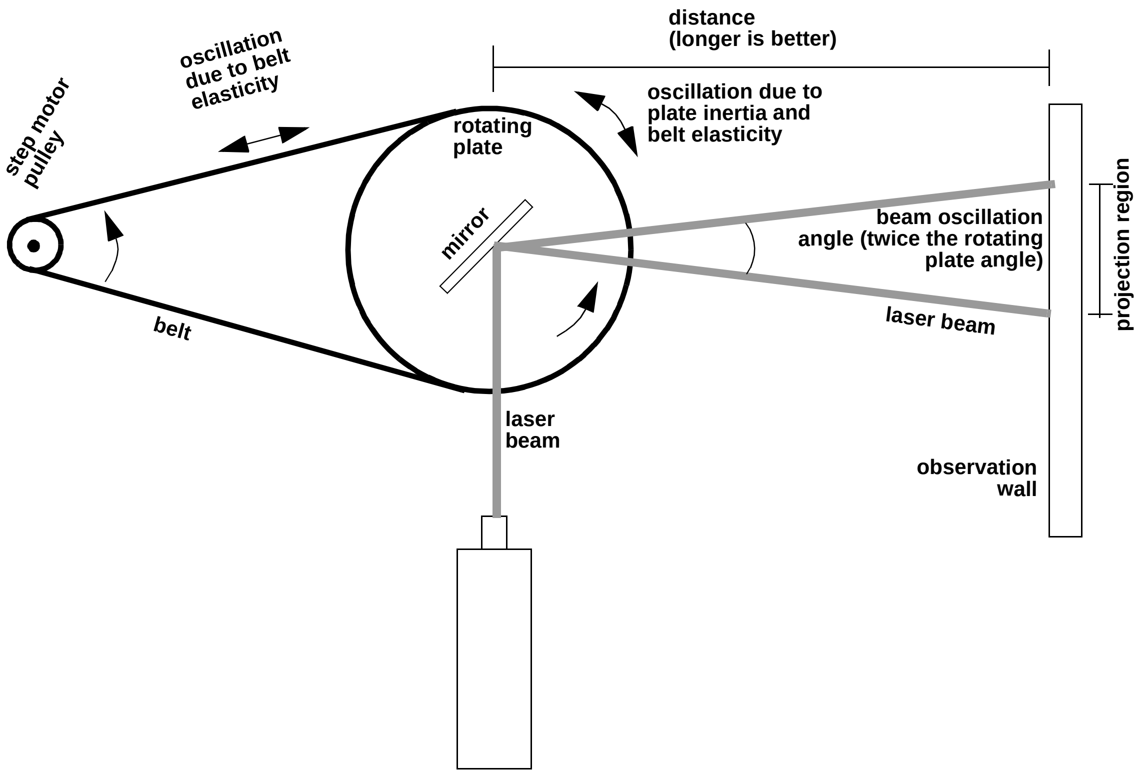

Figure 3: Laser experiment setup.

The diagram in Figure 3, though not exactly the correct illustration, gives an idea of what the second-generation Holoprojector looked like at the beginning of this work; as inherited from the previous prototype, the mirror sit on top of a PVC tube.

Speed was overcome by ridding ourselves of the floppy controller and its BIOS parameters. We used the standard PC parallel port to send signals to the floppy drive as needed (Figure 4), with total control over the timings involved. The minimum step time lowered to 5-6 *ms*, bumping up the mirror cycle frequency to the 180-200 Hz range [Ber98].

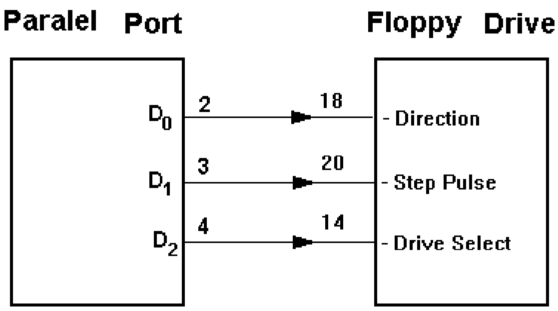

Figure 4: Parallel port to floppy drive signals pin connection.

To try and find out the determining factors for the poor dynamic performance in this setup, a separate experiment was assembled. In this case, a laser beam was projected to the reflector, which in turn projected the beam to a wall quite a distance apart, as is seen in Figure 3.

By shifting the *y* coordinate appropriately, we could then see what was really happening. We should have observed the behavior shown in Figure 5b, however what we got was more like Figure 5a. The result was caused by a combination of the elasticity of the belt and the inertia of the whole moving mass, including both the mirror and the supporting plate.

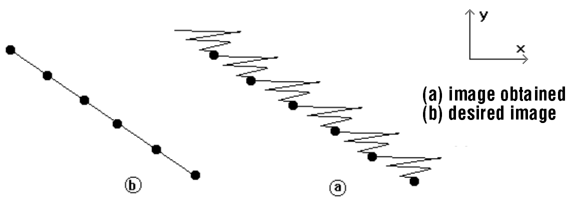

Figure 5: Results from the laser experiment.

The solution lay, obviously, in finding a more stable mechanical system, one that would not oscillate at the desired operating frequencies. Instead of relying on the belt assembly, we built from spare parts a more rigid mechanical transmission. It was made by fixing a somewhat long shaft as a diameter of the mirror's supporting plate, an end of the shaft fitted with a bearing, to reduce friction. The bearing was allowed to roll over the round edge of an eccentric pulley, which was directly driven by the step motor. Springs were conveniently fitted to enforce movement of the shaft strictly under the eccentric pulley command, in much the same way camshafts drive valves in a car combustion engine.

So much for elasticity, but the total mass was too high for the step motor to drive the motion. The solution was to improve every single piece in the moving assembly. In the end, an acrylic mirror was substituted for the glass one, and all heavy metal parts in the mirror fixtures were replaced by plastic and aluminum substitutes. Figures 6 and 7 show both a top and a side view of the assembly, respectively.

It is interesting to note that the new reflector assembly was much smaller than the original one, allowing for a closer mounting of the objective lens. The end result was the ability to illuminate larger scenes over the holographic screen. Figure 8 shows the first prototype holoprojector [Dia94], whereas Figure 9 shows the Holoprojector version 2.

4 Results

The first picture (Figure 2), for comparison purposes, is the first produced by the second generation holoprojector, whose mechanical instability is depicted at first glance. It corresponds to the skeleton of a cylinder made of 4 slices, effectively part of a single object. The refreshing rate was ≈28 Hz.

The following examples were produced with the final mechanical arrangement. A refresh rate of ≈12.5 Hz was chosen to allow individual slices to remain visible for around 20 *ms*, thus better impressing the image on the observer's retina. Scenes typically had an exhibition volume delimited by a height of 180 *mm*, a width of 150 *mm* and a depth of 70 *mm*. Measurement of the depth was done by having an observer watch the scene while an optical fiber with light leakage was held close to prominent features of the scene, in front of the holographic screen; as the object was moved back and forth, the observer would tell where that image feature and the object seemed to be at the same distance or depth from him/her. Also, when the image feature seemed to be behind the holographic screen, we kept the fiber in front of it, but used a small piece of holographic film to reflect the image of the fiber, as if it was actually behind the holographic screen. This yielded the same behavior as a fiber placed behind the screen, without the inconveniences this would bring to observation.

Takes (all taken in stereo pairs) were done at a distance of 720 *mm* from the holographic screen, with 135 *mm* between camera positions for the stereo effect. All stereo-pairs are shown in both divergent (pair to the left) and convergent (pair to the right) view. In some pictures, a pair of illuminated optical fibers were positioned to aid as a depth reference. The left one is circa 3 *mm* from the holographic screen, whereas the right one is circa 62 *mm* from it. They are some 100 *mm* apart.

Figure 10 shows a cube to be sliced for holoprojection and Figure 11 shows its reproduction on the Holoprojector.

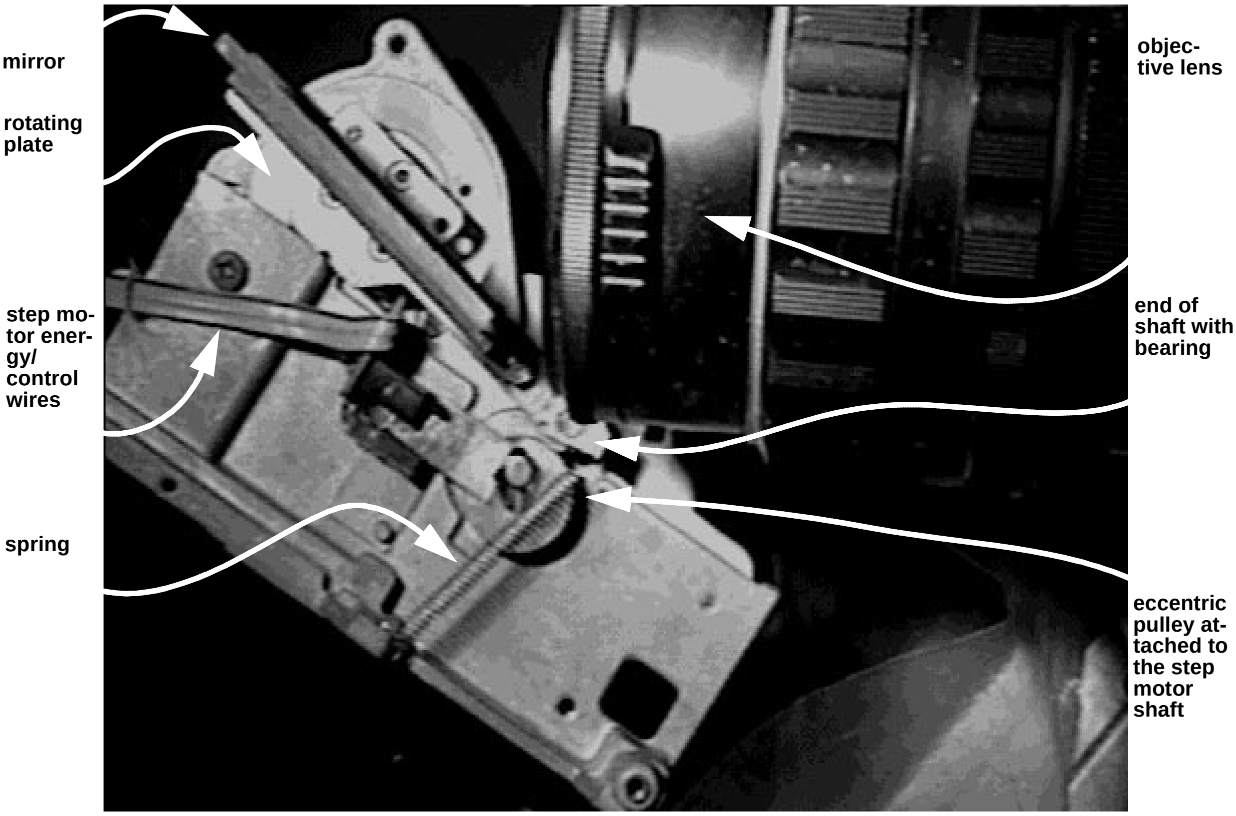

Figure 6: Reflector top view.

Figure 7: Reflector side view.

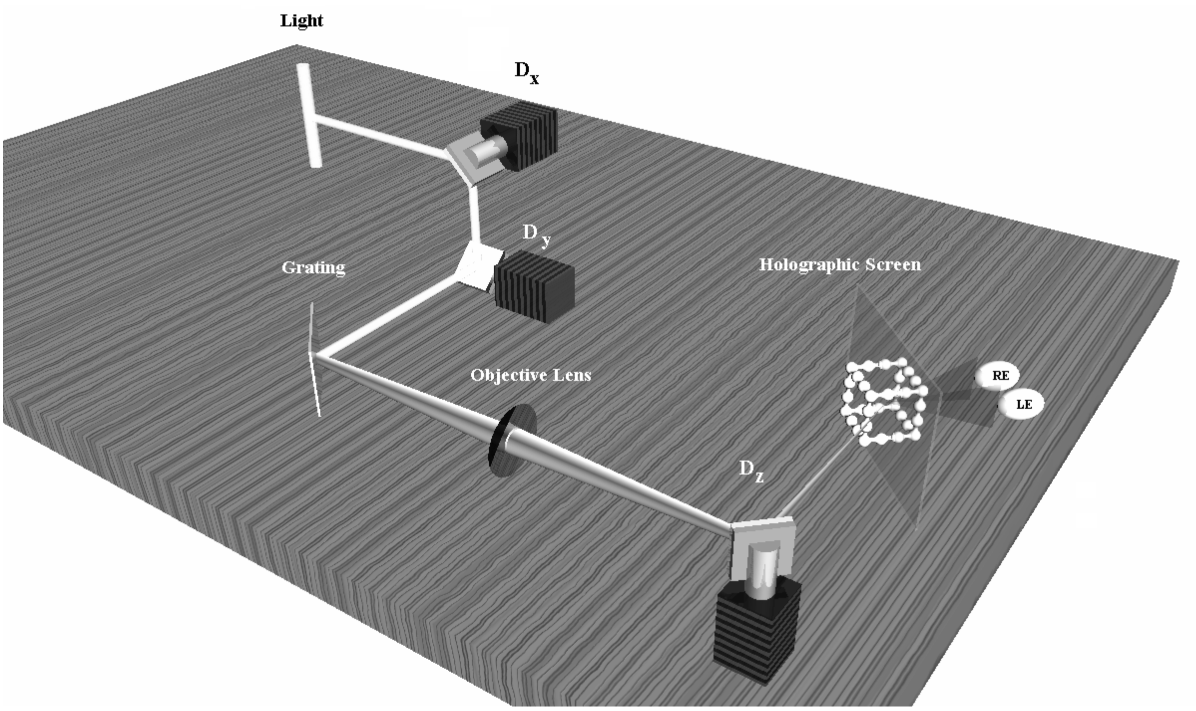

Figure 8: First Holoprojector prototype from Lunazzi and Diamand.

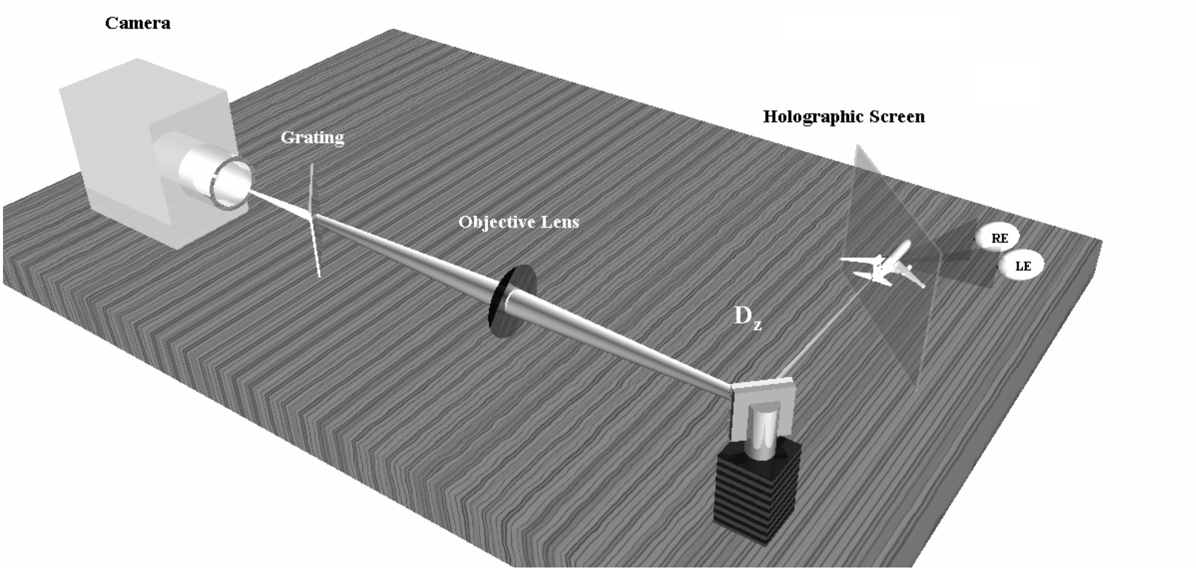

Figure 9: Holoprojector version 2.

The next pictures illustrate the slicing method as shown in Figure 1. Figure 12 is the original scene and Figure 13 is the reproduction on the Holoprojector.

Figure 14 shows the 3D version of the Fokker Dr I airplane (from *Red Barons*, by Julian Perez Serrano). Due to difficulties in capturing the images, the engine region looks closer than it should. Figure 15 is its reproduction. Figure 16 shows the original Klingon spaceship Bird of Prey, which is a nice example to illustrate depth; Figure 17 is its reproduction.

5 Conclusion

The system generates 3D images in an exhibition volume formatted in 2-D slices of a 3-D scene with continuous horizontal parallax, which can be observed without any visual accessories. The image slices can be shown at a

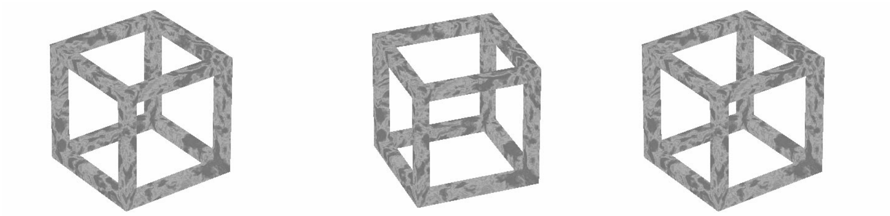

Figure 10: Skeleton of the cube to be sliced.

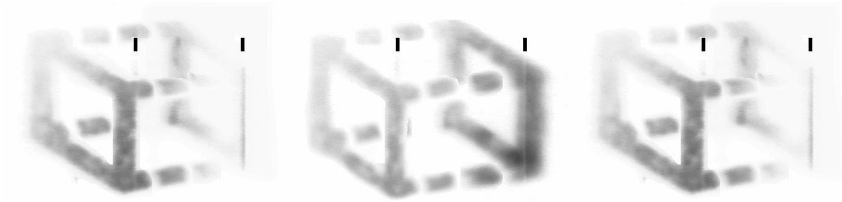

Figure 11: Reproduction of the cube on the Holoprojector.

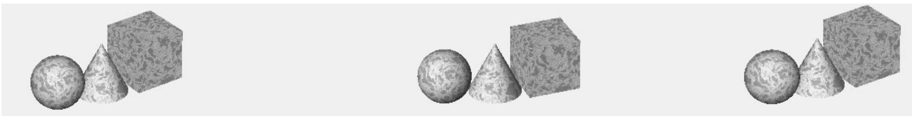

Figure 12: Original scene with a sphere, a cone and a cube, to be sliced.

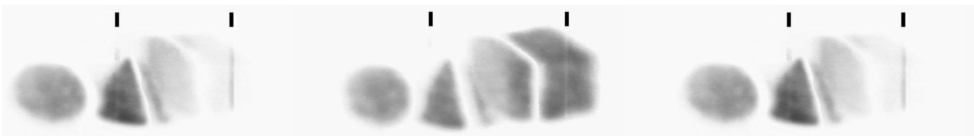

Figure 13: Reproduction of the sphere-cone-cube scene on the Holoprojector.

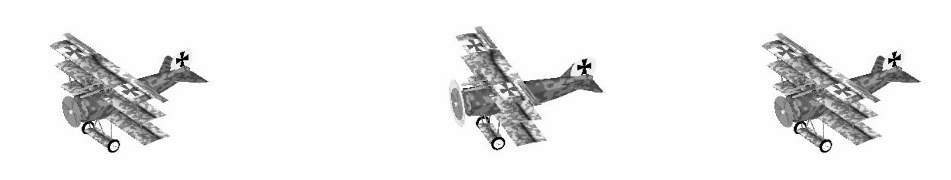

Figure 14: Original scene with the Fokker Dr I airplane.

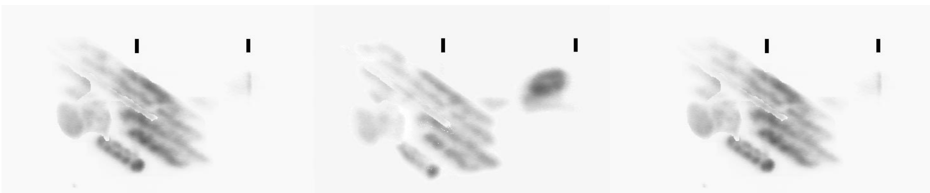

Figure 15: Reproduction of the Fokker Dr I airplane on the Holoprojector.

reasonable rate (14 Hz). The images can be observed at a distance of 1 *m* from the holographic screen, with a projection volume easily reaching $300 \times 140 \times 60$ *mm*. In fact, the latest setups currently in public exhibition can have an image area of 1000×700 *mm*. By design, there is no vertical parallax, but the horizontal parallax allows a 200 *mm* side movement by the observer. Flickering is still present given the current refresh rate. Scenes are monochromatic, since the color spectrum is used for depth coding with the holographic screen. Observers will notice tone variations as they move in relation to the holographic screen.

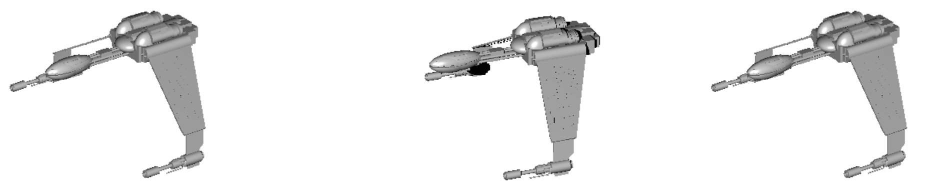

Figure 16: Original scene with the Klingon spaceship bird of Prey.

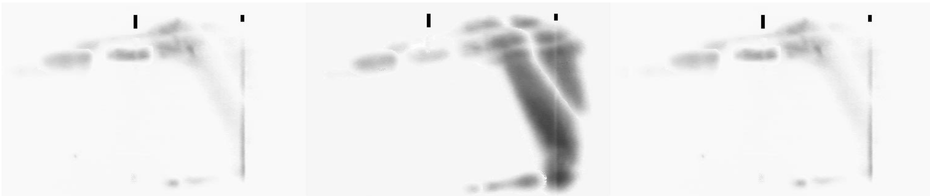

Figure 17: Reproduction of the Klingon ship on the Holoprojector.

The limitation on the number of depth slices and the refresh rate may be overcome by the inclusion of a new emergent display technology and of a new projection system. Already, there is in the market an LCD screen with exhibition rates of 1 to 2 KHz [Dod96]. The limitation would then reside on the data transfer rate. At a rate of 2 KHz our system may draw 3D scenes with 64 slices at a rate of 30 Hz, or 100 slices at a rate of 20 Hz, which is more than what is needed here. Clearly, the most obvious application of the Holoprojector is the one to benefit from such high rates: a holographic animation system. As it is, the Holoprojector is quite effective, yielding very good visual results in the latest setups. Unfortunately, verifying this claim cannot be done by reading this work alone, due to current printing technology limitations (will we ever see a 3D magazine/journal?); one has to physically visit our exhibition room.

It should be pointed out that the system is still under development, with new enhancements in both technology and techniques being worked on.

6 Acknowledgments

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