Holographic Moving Images

by

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Abstract

I constructed a holographic moving image machine, - - the holographic praxiniscope - - to explore high resolution, white-light, full-parallax, three hundred and sixty degree holographic imagery in motion.

Thesis Supervisor: Stephen A. Benton
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Chapter 1

Introduction

We receive more information with our eyes, in the form of images, than with any of our other senses. The absorbtion and processing of that information, in order to create, communicate and store those images, through the use of tools, has been around for fifteen thousand years. In the past one hundred and fifty years, we've accelerated the development of new imaging tools - with photography, film, video and computers - and continue to refine the simulation of reality. Holography to date, is the closest we've come to this realization. I believe the next frontier will be holographic moving images.

In my research I created a machine for viewing full parallax, white light holographic moving images. The machine was modeled on a nineteenth century moving image device, the praxiniscope. Although the moving holographic imagery cannot be shown within this written explanation, documentation of the machine is included.

In researching earlier moving image devices I became interested in the history of ideas leading up to the creation of these machines. I believe it adds insight into the technology we sometimes take for granted today. The exciting new technology of holography is the key element to the thesis and is what makes this a unique investigation. Seeing a hologram continues to be an amazing experience. Holography is not easy to understand for anyone who has not been exposed to the process or studied physics. I felt a strong urge to write a simplified explanation of the process because you can appreciate what you're seeing much more if you understand it.

I learned two things from the historical research into holographic moving imagery. The first was that the investigations were quite extensive and researchers were not only adapting the new technology to existing ones but pushing the optics into new territory. The second was that the machine I created had very important information to contribute to the field.

One important area that unfortunately is not addressed in this thesis is the imagery of the holograms. In using highly developed technologies we tend usually to spent more time getting to the image than thinking about it. The need for a strong interest and committment to develop images for these new technologies is crucial for their existence and the communication of information about the world in and around us.

Chapter 2

Moving Imagery

2.1 Historical Background

2.1.1 Pre-Nineteenth Century

The history of ideas and inventions leading to the discovery and recording of images in motion is difficult to trace. There are some key ideas and inventions which led up to the nineteenth century when many of the current technologies began. The first depictions of motion came as early as recorded imagery itself in the form of sequential cave drawings. Probably the first ideas for capturing and using reflected light are in an observation by Aristotle in 340 B.C. and later in theoretical detail by Leonard DaVinci at the beginning of the 16th century.

What DaVinci described, basing his findings on studies of the human eye, was the "dark room" effect or *camera obscura*. If a small hole is cut into the wall of a dark room, and if the sunlight is strong enough, light falling on a scene beyond the room is projected upside down on the wall opposite the hole. Around the same time as DaVinci's *camera obscura*, the basis for photography, the *camera lucida*, was invented[1][2]. It was a box which used prisms and mirrors for making drawings from virtual images of real objects. A version of the camera obscura eventually emerged which went from room size to box size and was perfected by the end of the seventeenth century with optics and mirrors similar to current single lens reflex systems [3][fig. 5.1].

Another notable seventeenth century invention was A. Kircher's magic lantern which was for large audience projection through the twentieth century. Hand drawn projected entertainment became very popular as a result of the magic lantern but it was not until the early eighteen hundreds that ideas about motion and photography became a reality [4].

2.1.2 Ninteenth Century

In 1824, P.M. Roget, famed for his Thesaurus, read a paper outlining the phenomena of the persistence of vision, wherein our eyes retain for an instant an image, and see motion by the superimposition of sequential still images. His theory sparked the invention of countless devices and toys demonstrating the effect. These included the thaumatrope (Paris '25), phenakistiscope (Plateau '32), strobeoscope (Von Stampfer '32), and zoetrope (Horner '34), as well as the phantascope, mutoscope, tachyscope, zoopraxiscope, and finally the praxiniscope (Reynaud '77) [5][6][7].

The simplest of these devices, the thaumatrope [fig. 5.2], was a paper disc that contained two images on either side: a bird and a cage. Two strings were attached and when they were twirled the two images were super-imposed. A more complicated device, the zoetrope [Fig. 5.3], still popular today, is a drum shaped device with strip drawings on the inner wall. Looking at each drawing through slits in the drum opposite them, a shutter essentially for minimizing motion blur, one sees each image for a fraction of a second, retains it after the slit passes, and when the next image in a series of motion depiction replaces it, again the superimposition and creation of motion.

2.1.3 The Praxiniscope

The most advanced device of this time, replaced only by motion picture films as we know them today, was the praxiniscope [fig. 5.4]. Invented by Emil Reynaud in 1877, the praxiniscope replaced the slit viewing technique of the zoetrope with a core of angled mirrors opposite each drawing [8]. One viewed the turning reflected images which "..had the illusion of smooth flickerless motion" [9]. The first praxiniscopes were table top devices. Later they were combined with more complicated optics and mirrors to adapt the magic lantern system for large audience projections[Fig. 5.4]. Screened in a theater some of the elaborately hand drawn films were fifteen minutes in length. They were never combined, at that time, with the flourishing art of photography.

2.1.4 Twentieth Century

It was not until Eadweard Muybridge and E.J. Marey that the connections between photography and motion started to become a reality and inventors like Edison, Eastman, Armat and Jenkins set to work on various recording and projection devices [10]. There are still many unanswered questions about who is actually responsible for particular devices and which came first but the developments continued until a major slowdown occured due to patent wars. Further developments continue still despite the invention of that miracle of transmission - television.

Just as for the motion picture industry, tracing the evolution of the invention and development of television is an arduous task but a few interesting facts about the early days should be highlighted. A surprise perhaps, is the fact that television was conceived of in the mid-ninteenth century by a physicist, A. Bain, and that the first transmission of an electric picture was in France in 1862. Even before motion pictures became popular or Marconi had used the wireless, the German inventor Nipkow had invented a rotating perforated scanning disc capable of breaking a scene into points of light for transmission [11]. Many people and remarkable breakthroughs were involved in the first half of the twentieth century during the development of television.

Currently the two most sophisticated developing moving image technologies are computer generated graphics and holography. Though not at its full potential, some computer generated imagery in animation is the most fascinating imagery we have today. The imaging promise still as yet inconceivable of holography is only beginning to be realized. The combination of both is predictably the next goal.

Chapter 3

Holography Background

3.1 Survey

Although only forty years old, the field of holography has developed into areas too numerous to mention in this brief outline. I would like to review holography's earliest years, then try to write a simplified explanation of the process and highlight some of the important developments in imaging technologies. At this time, a definitive text explaining current uses and techniques has not yet appeared, but most of the research material is available from conference proceedings and a few texts that will be mentioned in the bibliography section.

In 1948 Dr.Dennis Gabor published " Image Formation by Reconstructed Wavefronts", the first paper describing the process later to be called holography. Gabor was working on improving imaging techniques for the electron microscope when he conceived of a way to record three dimensional information. It was to be more than a decade later before truly photographic quality holograms could be viewed due to the invention of the laser and the researchers who used it, Drs. Emmett Leith and Uris Upatnieks', who were working in the field of radar research at the time. Leith and Upatnieks work triggered the first big wave of activity in the field by optics, physics, and communications researchers [12].

3.2 The Process

3.2.1 Why It Works

In order to fully appreciate what happened next historically, it is necessary to explain how holography works. I have found that one way to explain it is to think first about known imaging processes like our own eyes or photography. Although different from holography, they involve some of the same ideas. When light hits an object it is scattered by that object in many directions, some in our direction and our eyes are able to receive the light, shrink and flatten it optically to be received by our retinas, and store it bio-electrically. In the case of two eyes we receive light rays from two different directions and through the processes of convergence (the angular alignment between the rays) and the process of accommodation (focusing) we can see the object in three dimensions.

When we record something photographically it can be compared to the one eye system where we are bending the rays with a lens and focusing them to the size of a small piece of photographic film in our camera to be chemically stored. When we record something holographically it is similar to the two eye system in that we record the direction of the light rays, but the holographic process goes beyond the two views (or stereoscopic vision) to give us all the views of the object and we are able to store all that information on the one piece of photographic film.

3.2.2 How It Works

How images are stored holographically depends mainly on three important things. One is the recording technique called interference, two is the playback technique of diffraction and finally what make these work is the use of a coherent light source in the form of a laser.

When white light hits our object and is scattered, that light is made up of many different wavelengths from the visible electromagnetic spectrum, and is incoherent. When laser light hits our object it is made up of a single wavelength of light which still allows us to record information about light and dark areas on the object and more importantly allows to capture the exact three dimensional shape of the light wave coming from our object through the process of interference.

When making a hologram a recording is made of two beams interfering with one another on a high resolution photographic plate. Both beams are split by optics from the same laser and are in phase. One of the beams, called the object beam, hits the object and scatters light towards the plate. The other beam, called the reference beam, sends light from one direction only and is used as a reference for the object light. The reference beam is used again when the plate is developed as a reconstruction beam. The reference light is sent to the plate from the same direction as when it was recorded, and through the process of diffraction our object light is replicated. The reference beam in effect reads the complicated interference pattern and diffracts the original light back exactly where it came from in space. Through this lensless process the image we see is the most exact replication of an object yet developed.

3.3 Display

Compared with other imaging technologies, there are a number of very specific constraints on the kinds of holograms that can be made and displayed. The recording process requires complete vibration isolation and therefore limits the recording of living things (except with an expensive pulse laser). Size is another problem, currently being worked on, as well as color and image quality.

The first holograms were viewable only in dim laser light. It was only after the pioneering efforts of Denisyuk in 1962 and Benton in 1968 that white light viewable holograms are available. The possiblities that were triggered from these developments have made holograms easier to display, have spawned more possible directions for the holographer to explore, and more awareness by the general public. Fortunately the written material on this subject by S.A. Benton is the most conclusive to date [13][14] [15].

Chapter 4

Survey of Holographic Moving Images

4.1 Early Work

> ... *"the creation of a picture in which all perceptual conventions are eliminated and in which the viewer in a sense becomes a full and equal participant in the scene. It would be difficult to exaggerate the effect a picture of this type can have on the mind of the viewer."*
>
> Denisyuk [16]

The interest in realizing holographic motion pictures is not only the concern of the dream makers in Hollywood and Disneyland but also of researchers in the field. Many were eager, in the late sixties, to apply the recently developed imaging techniques of holography to the existing technology of motion pictures. Although prospects for the merger of television and holography seem to be in the far distant future [17][18], the application of cinematographic techniques to holography has been significant as will be reviewed shortly.

4.2 DeBitetto's work

Of the early work investigating holographic motion pictures, most notable is the work of D.J.DeBitetto. While working on bandwidth reduction problems[19], DeBitetto came up with a very interesting method for recording and reconstructing moving images. The bandwidth reduction research and subsequent elimination of vertical parallax in the form of hortizontal slit recordings led DeBitetto to his first motion application. He recorded a series of hortizontal strips of sequential movements of objects [20]. The ten centimeter long recorded strips made for two eye viewing, were of back-lit objects placed on a turntable and rotated every three degrees.

The reconstruction of the imagery was done by running film at a constant velocity through a laser illuminated viewing aperture, creating a vertically scanned but visually stationary image, without the need for a shutter. A year or so after DeBitetto's first movie was documented in 1968, he used a more powerful helium neon laser that allowed him to create a front-lit holographic movie, with increased object to reference angle for better image quality. He created 960 strips for the three hundred and sixty degree rotation of two figures 25 cm apart. Viewing the reconstruction of the movie through the film DeBitetto found " The stationarity of the image, i.e., the degree to which the direct-viewed virtual image remains stationary with the strip hologram in continuous vertical motion(at speeds of 76 cm/sec.) was found to be excellent" [21].

4.3 Identification: Problems/Restrictions

DeBitetto was probably the first to view holographic moving imagery but his system was limited by many of the restrictions of display work at the time; size, laser-light viewable only, viewing zone limitations and distortions.

One other project to mention, which was also done in the late sixties by the team of Jacobson, Evtuhov, and Neeland [22], was a holographic motion picture system which recorded live action using a repetitively pulsed laser. Although not as holographically unique as DeBitetto's research, the Jacobson team had a 70mm film camera adapted, and holographic film sprocketed to record fish swimming in an aquarium. Back-lit because of power and coherence limitations the work had some minor synchronization problems but the recording was successful.

These first efforts at holographic moving imagery were promising but clearly demonstrate many of the restrictions compared to existing systems. First, if more powerful pulse lasers were accessible shooting live action of unlimited size would not be a problem. Second if the one to one size relationship between image and holographic recording could be optically solved then the film size could be smaller and it would be cost and equipment effective to shoot. Third, in addressing the limited viewing zone for viewing holographic work, if the projection optics for large screen viewing could be built, then the experience as Denisyuk said "could not be exaggerated."

The problem of reducing the amount of film required while keeping the image the same size was addressed by Leith, Brumm, and Hsiao. They recommended a scatter-plate system and a large lens system. Both methods have great potential as well as problems. The most acute problems are the decreased image information in the scatter-plate system and the limited viewing zone of the large lens system [23].

Denisyuk addressed the problems of recording holographic movies in a very clear introductory paper covering general issues [24]. He points to the necessity of recording in non-coherent light and thinks adaptations of Lippmans integral photography would work. He suggests synthesizing views from photographs recorded at limited angles of view utilizing optical and computing technologies. Finally, he predicts that the costly process of duplicating holographic movies for distribution could be made cheaper and easier by the currently developing embossing technologies.

4.4 Komar the Barbarian

The most ambitious and thorough investigation to date into the possiblity and the creation of a holographic projected motion picture to date was done by a team of Russian scientists lead by V.G. Komar. Determined to open holographic movie houses within a few years of initial efforts [25], they announced and screened the first movie at a SMPTE (Society for Motion

Picture and Television Engineers) conference in 1976 and publshed their findings in a paper edited by S.A. Benton in 1977 [26]. The screening of the thirty second loop of a woman placing jewels in a wine glass had the disappointing property of being viewable by only four people at a time.

Komar's effort to solve some of the basic holographic-cinematographic problems was significant, although many problems still exist. His team also addressed some of the above mentioned issues: recording on a small piece of film for ease of transport and economy, and being able to project the image to a large audience (their goal is 200). They acknowledged the need for multi-color pulse laser recording of large scenes and the development of more sensitive film for these multi-wavelength recordings. They mentioned the need to develop a screen (mentioned by Leith et al.) that has the capability of focusing and multiplying the holographic image. Coherent and incoherent recording methods were also looked at and some suggestions made for composite recording of both for special effects.

Optical and non-optical methods for duplicating films and lenticular raster plate non-coherent recording methods are under investigation. The Russian group considered the actor's health in the pulse laser recording studio by using low ambient light when shooting scenes. They also discussed the adaptability of the current stereoscopic (Stereo70) film to their system as well as its compatibility with three D television systems.

Komar's exciting work is continuing in the USSR, and has very little competition. There is considerable projection research going on in Japan [27], and a holographic movie display is currently running in Paris at the Museum of Holography. Although there is not much information available about it, it is possibly based on the system presented first at the Hugot Foundation of the College of France [28]. It was described in an article in a Japanese magazine as being a large projected holographic loop which displays imagery of birds in flight.

Chapter 5

The Holographic Praxiniscope

5.1 Objectives

It is important to continue investigation into holographic moving imagery to be able to glimpse what this future technology might look like. The most direct way to appoach this is to incorporate holographic imagery into an existing technology. The way I have proposed to do this is to build a motion picture device which is modeled after an earlier nineteenth century machine, the praxiniscope, and replace the images with holograms.

Some of my interest in this direction comes from my earlier work in video and animation, and in moving old media through new technologies. The building of the holographic praxiniscope is in part moving new media through an older technology. I believe this process will trigger questions and answers about the inevitable future of holographic moving imagery.

What makes this machine different from some of the previously developed work in the area? I think the focus on realizing full parallax, high resolution, white light viewable, smooth flickerless motion is something that has not yet been attained. The experience of seeing something that has never been seen before was a strong underlying motivation. It combined interests in machines and imagery - devices which create illusion - and the possibility of extending the holographic illusion into a new realm.

5.1.1 Why a Praxiniscope?

I chose Reynaud's praxiniscope over the zoetrope and others for several reasons. The shuttered drum system of the zoetrope had many more restrictions on the viewing zone and illumination placement due to the fact that in order to view the holograms with two eyes the slit would need to be horizontal and the drum would have to be vertical mounted. This would end up more like the DeBitetto reconstruction, and thus suited only to horizontal parallax only transmission holograms.

Another device proposed by fellow student Karl Sims was based on a system known as the Mutoscope[Fig. 5.5] In the Mutoscope, images, more familiarly photographs, are attached to a core. Specifically the bottom of each image is attached to the core, and as the core turns, the cards flip. A coin operated machine was generally the most common type of Mutoscope. I can see practical problems with this device for holography, as it would be difficult to mount glass plates or holographic film to a drum. There are however interesting illumination possibilities with the Mutoscope.

In the praxiniscope[Fig. 5.4] reflection-type full-parallax holograms are reflected from mirrors in the center of the device. The mirror core turns, one mirror is replaced by the next mirror, and the holograms move and turn as well. Because holograms effectively have built-in shutters in the form of a narrow viewing zone, because the images turn the shutter is not necessary. If several holograms are illuminated then several viewers can view the machine working simultaneously.

5.2 The Machine

5.2.1 Design and Construction

The machine I constructed is made up of a platform which sits six inches above a table. Centrally located on the platform is a bicycle wheel (approximately 25" diameter), mounted hortizontally, which has been specially machined and adapted to mount plate holders for eight holograms on the rim. The hub of the wheel is also modified to hold an octagonal aluminum platform (approximately 12" diameter), on which eight five by five inch mirrors were mounted. A sixty rpm motor geared down about 1/3 rpms (and two cooling fans) is attached under the platform to drive the bicycle wheel with a simple pulley system and a variable speed attachment allows speed control [Fig.5.6].

To prevent extraneous reflections off the mirrors some parts of the machine are painted black. Construction details also include raising the central mirror system so that the viewing zone is not be obscured by the holograms' reflection in the mirrors. The plateholders on the rim of the wheel were designed to prevent the holograms from flying out by allowing room for a thin right-angled attachment epoxied to the bottom of each plate. [fig. 5.7]

5.2.2 Why The Praxiniscope Works So Well

In order to view the image in three dimensions the width of the holograms and mirrors have to be wider than the distance between our eyes. A five inch mirror was chosen for this reason, and by splitting the twelve inch radius of the wheel to get the correct mirror placement (half-way between the rim and the center) we end up with eight mirror-hologram pairs [Fig. 5.8].

The distance between the holograms and the mirrors is a major factor in making this device work well.The mirrors should be halfway between the hub and the rim of the wheel, to place the visible image of the holograms at the hub. In this case the radius of the wheel is twelve inches, so we have six inches from the hub to the mirrors and six inches from the mirrors to the holograms. Another way to describe what happens is that the image on the holographic plate is reflected in the central mirrors, and the image is seen with the added six inches of distance between the hologram and mirrors therefore the image is place at approximately the center of the wheel [Fig. 5.9].

The illusion of a turning image at the axis of a wheel is better than if it was on a flat screen system, because the angular rotations of the image around its center is matched by the device. Therefore the placement of the image in the plane of the hologram was important.

5.3 The Holograms

I decided to use image-plane reflection-type holograms for the machine for several reasons. First, they are full-parallax, white-light viewable with high image resolution. Also, this type of hologram is front illuminated and has a black back coating. The transmission type of hologram, on the other hand, would have reflection problems from the central mirrors since the illumination is through the plate. The image plane transfer is a two step process and allows you to place the image in front, behind, and in the plane of the hologram. This is very important for the correct placement on the machine.

5.4 The Results

5.4.1 The Good News

It works. The hologram is illuminated, a switch is flipped, and you see smooth transitions as images change through the turning mirrors. There are bright images floating at the center of the wheel. The machine is mechanically sound and easy to operate. The changes of position from image to image are much greater than they should be, but the praxiniscope provides a very strong sense of full motion in three dimensional space, and it is exciting.

5.4.2 The Not So Good News

The first improvement for the praxiniscope will be to create a new set of images. As mentioned above, image fragmentation caused by recording the eight holograms with forty-five degree rotation transitions was too much (especially with object rotation in the Z axis where the front and the back of the object rotate different amounts). Some computing correction would easily solve this problem. In addition the object-image construction (molecular-like structure) was too ambitious for the viewing space. Registration which is generally a problem in two dimensional animation is multiplied here but the stabilization requirements for shooting holograms can be beneficial.

5.5 Conclusions

I think the holographic praxiniscope could be modified in many ways that would lead eventually and easily to an important moving image projection display. Existing holographic projection research could be adapted to the machine generating new reflection optical elements. Also a film transport could replace the wheel and longer displays could be made. Walter Bender suggested color matching could be experimented with, which would lead to some interesting insights into full color reflection holograms. With slight design modifications the praxiniscope could be used in the lab to speed up the recording process and bring it into the twentieth century [Fig. 5.10].

Some of the most interesting work going on currently in holography, here at the Media Lab, is computer generated holograms. These holograms could easily be displayed on the holographic praxiniscope. This would enable three hundred and sixty degree full-parallax displays of things still in the design state, - macroscopic models of things we can only imagine with computers, - images of other planets, - and medical images from the latest imaging machines.

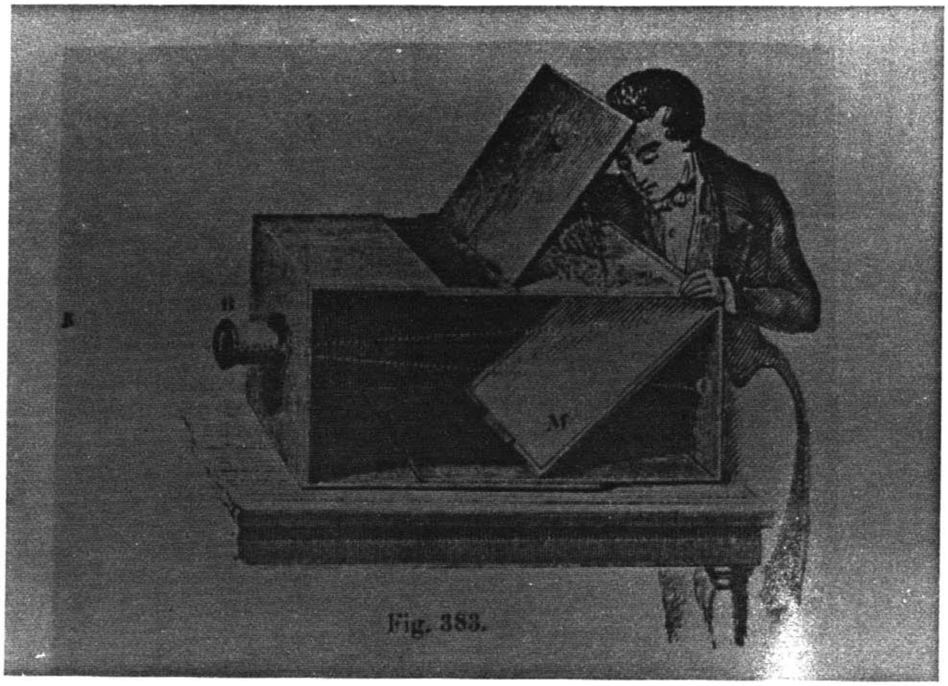

Figure 5.1: Camera Obscura

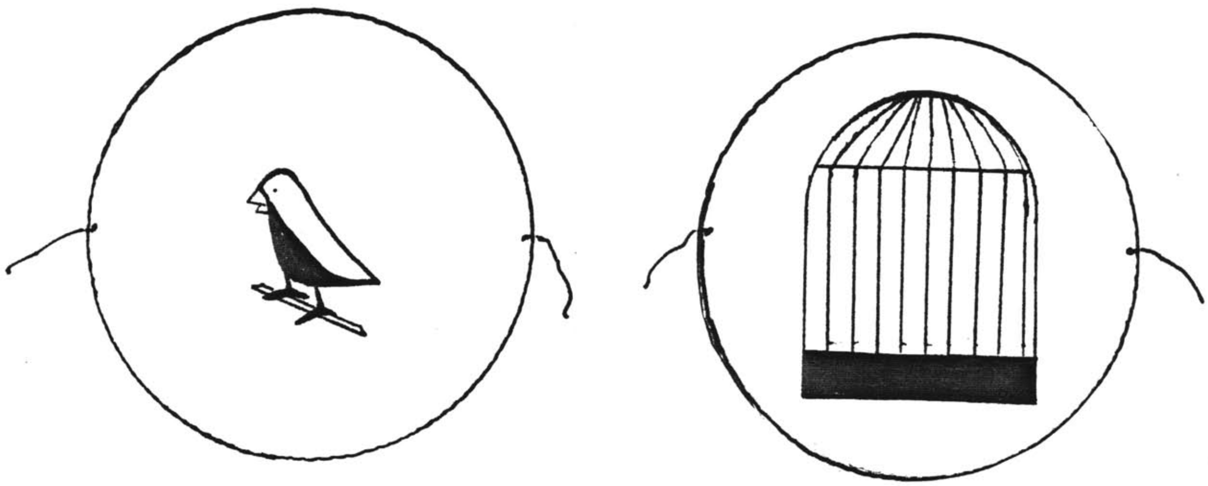

Figure 5.2: Thaumatrope

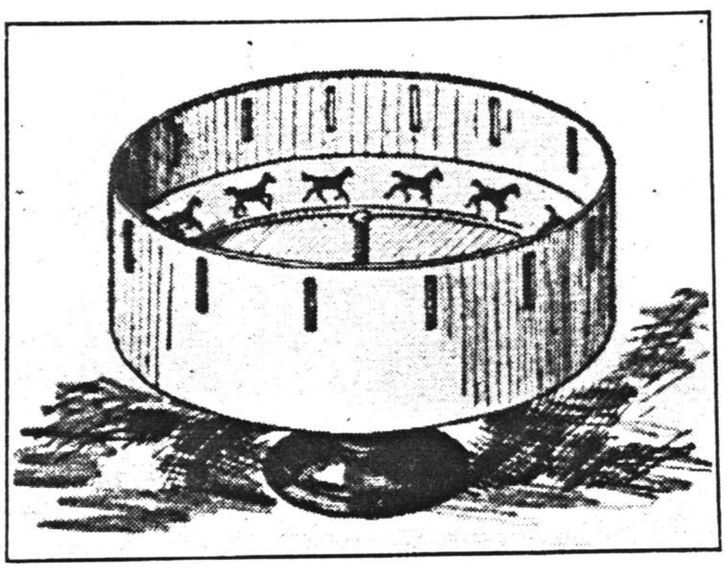

Figure 5.3: Zoetrope

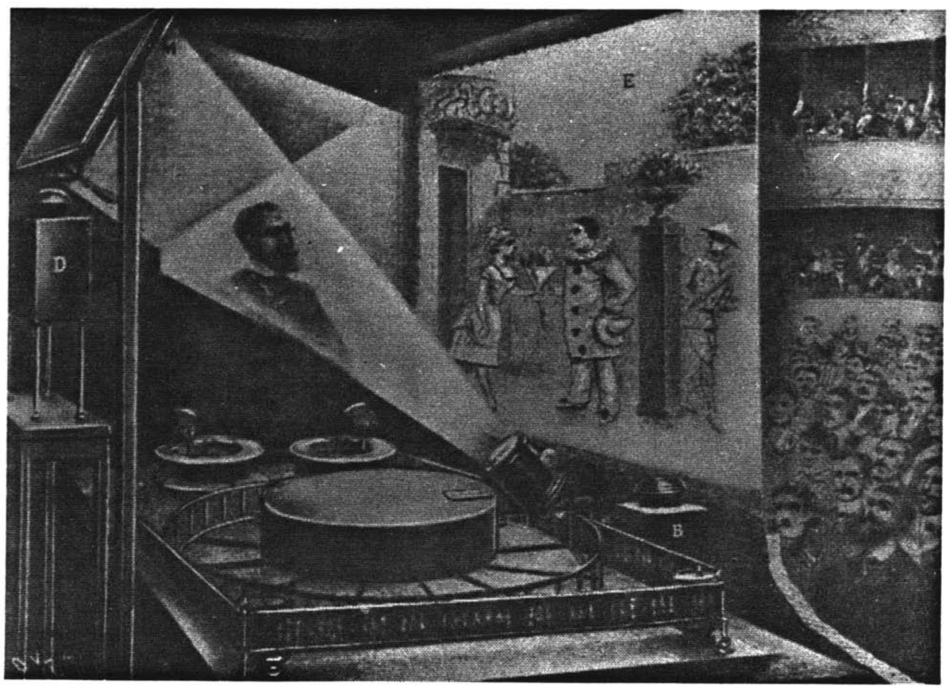

Figure 5.4: The Original Praxiniscopes

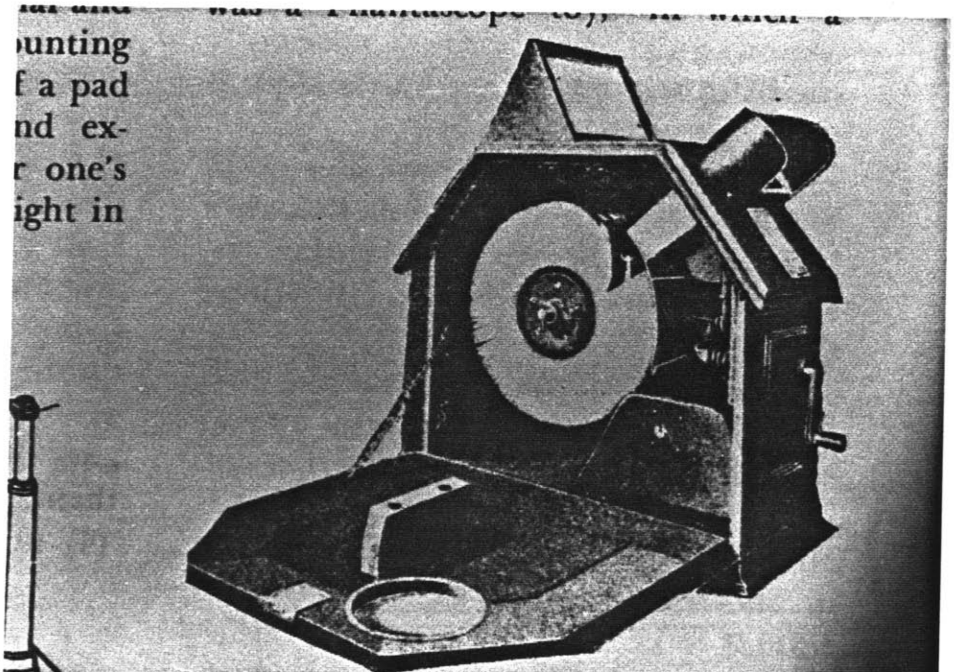

Figure 5.5: Mutoscope

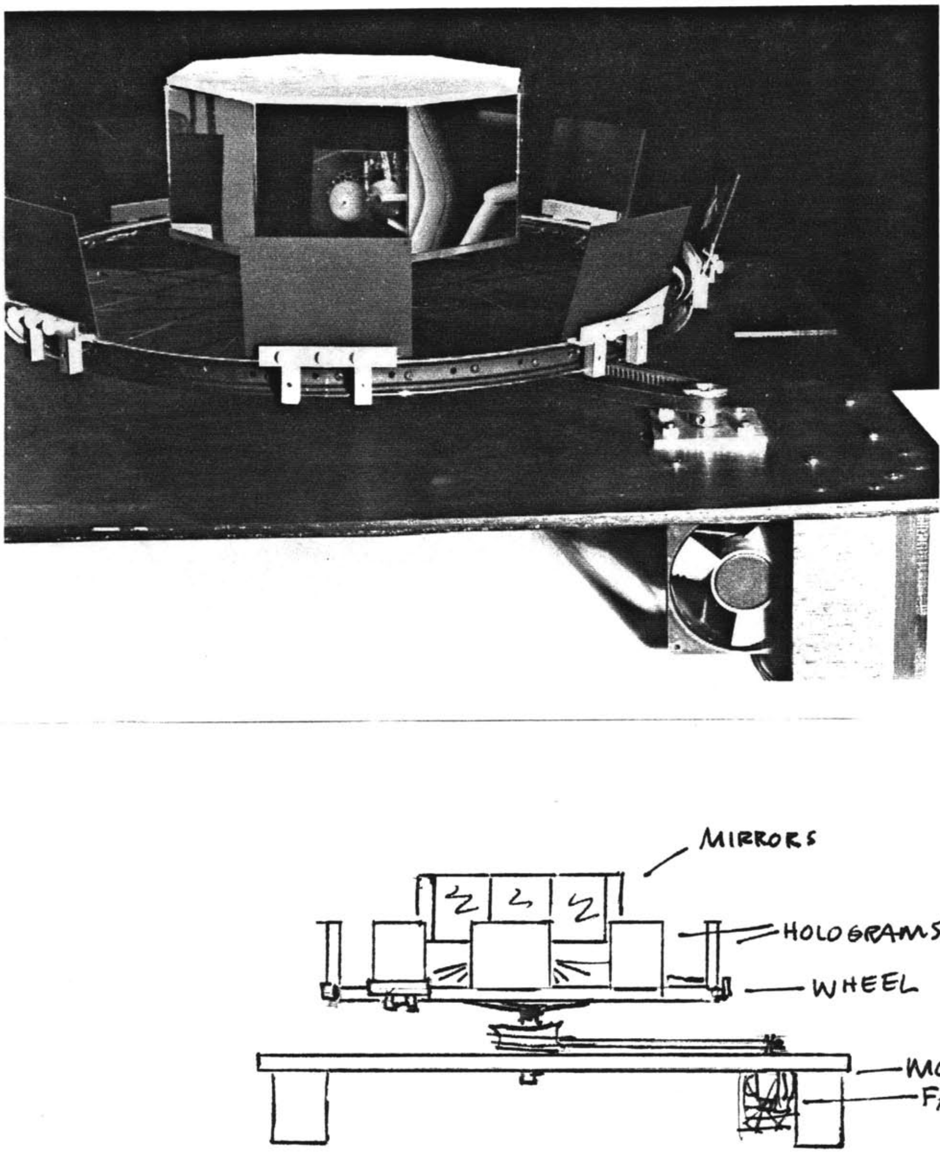

Figure 5.6: The Connors Praxiniscope

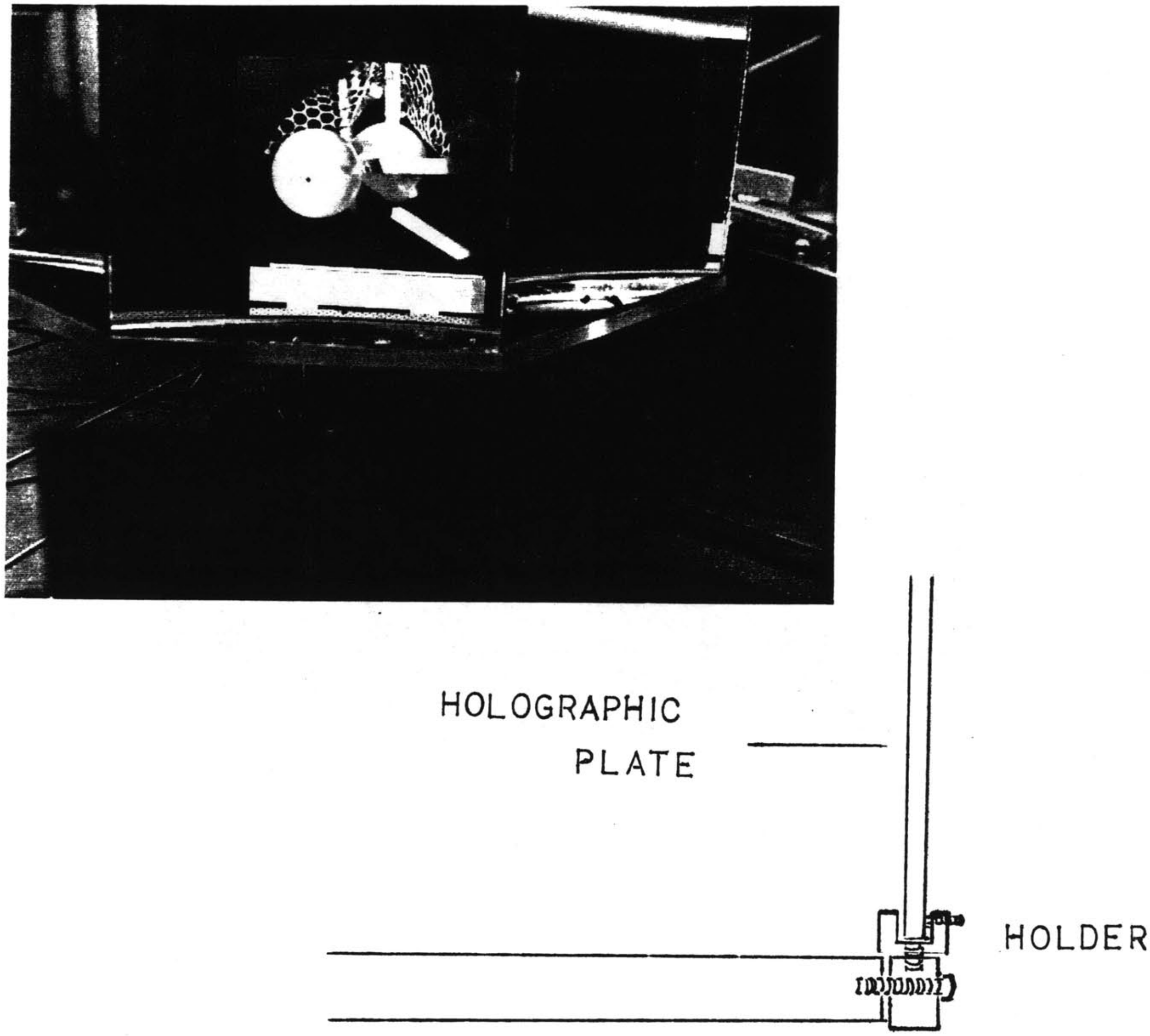

Figure 5.7: The Connors Praxiniscope: Detail

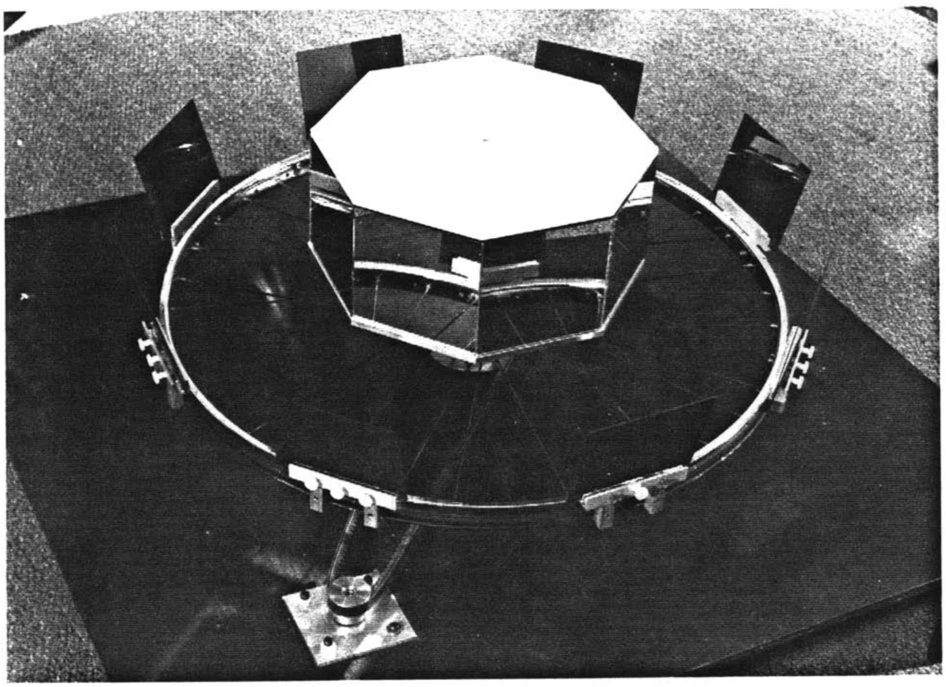

Figure 5.8: The Connors Praxiniscope: Detail

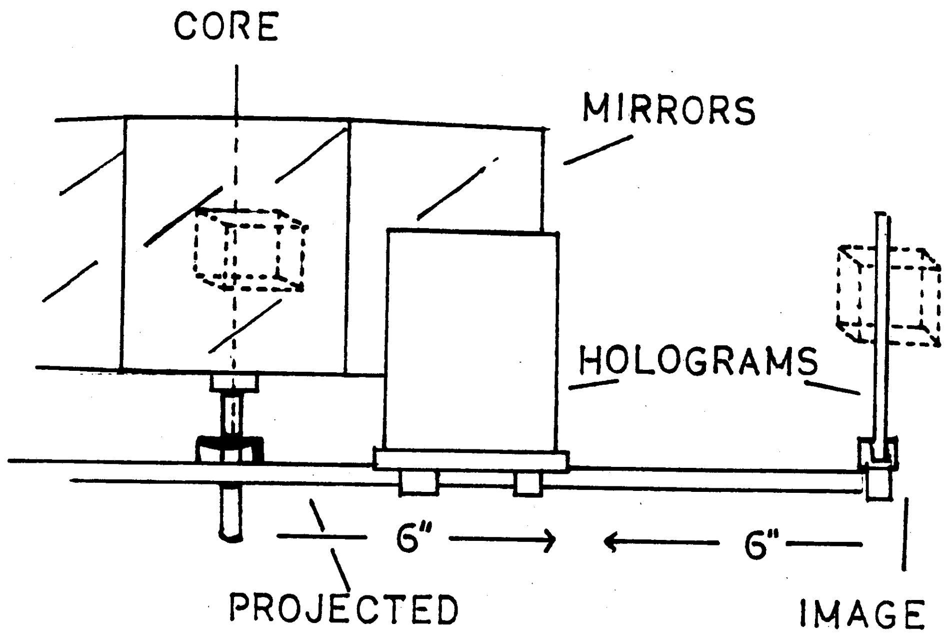

Figure 5.9: The Connors Praxiniscope: Detail

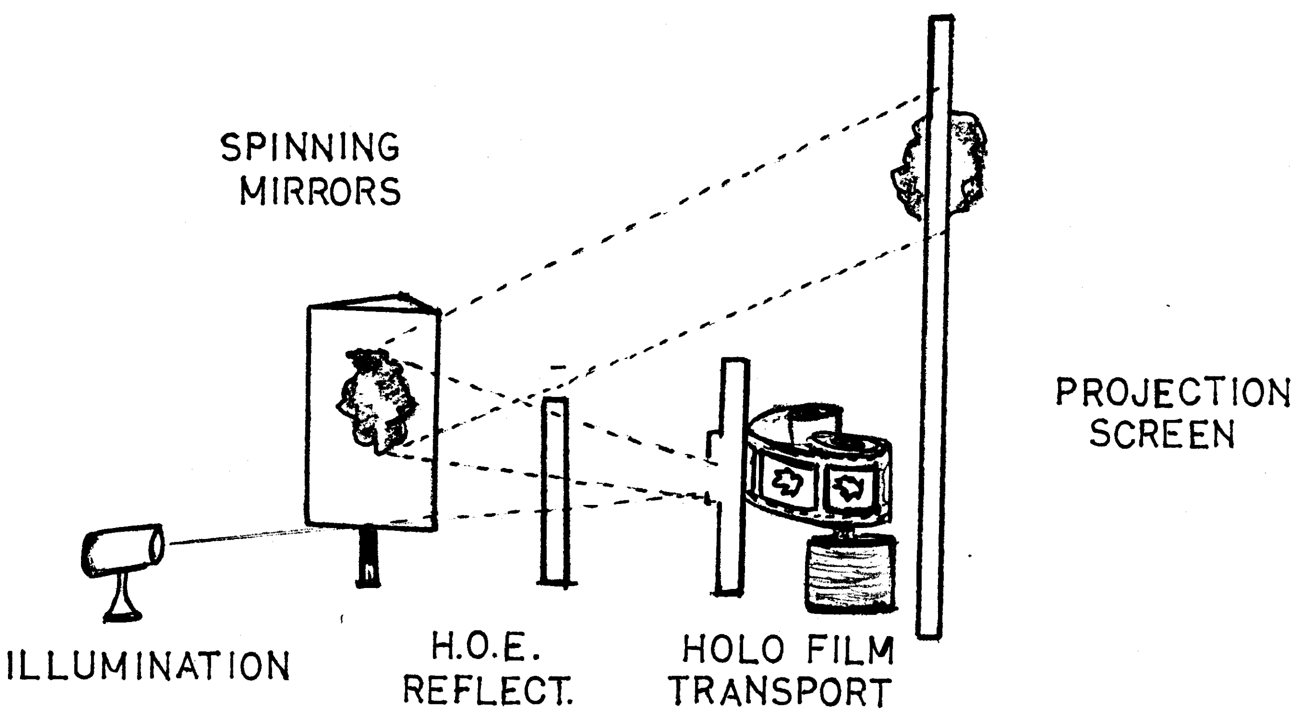

Figure 5.10: The Connors Praxiniscope: Future

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