MICROCOMPUTER CONTROL
OF A
THREE-DIMENSIONAL STEREOSCOPY

by

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I dedicate this to Frank E., Betty A., Ronald E., Nancy K., and David H. They know who I am talking about.
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I. INTRODUCTION

Overview

Viewing exterior surfaces of the body yields little information about the internal complexities of the human anatomy. The development of diagnostic imaging systems, using x-rays, has significantly contributed to the advancement of medical knowledge. Today's methods of radiological analyses are based upon two-dimensional imaging systems. The limitations of two-dimensional viewing systems can be paramount. A three-dimensional structure, such as the human body, projected upon a single plane has no premise of depth. All shadows appear as if they intersect. No information pertaining to spatial order is available. Through stereoscopic visualization the shadow images, obtained by radiographic analysis, can be placed in stacking order.

The study and diagnosis of anatomical systems is possible through present radiological techniques, i.e., x-ray film and fluoroscopic techniques. Several aspects of three-dimensional fluoroscopic information, however, provide the physician with anatomical information that can not be conveyed through the use of any other system. Three-dimensional fluoroscopy can provide real-time analysis showing spatial interdependence and motion. Through the observer's ability to perceive depth, the relative location and motion of objects can be differentiated. The value of stereoscopic and fluoroscopic information has been evaluated (1-11), and particular application has been shown in clinical procedures such as foreign object location,
hip pinning, cardiac catheterization, gastrography, angiography, or any process involving motion.

Specific reference has been made to the clinical aspects of stereofluoroscopy, but application to educational and industrial uses should not be underestimated. As an educational tool the student would have the opportunity to study the interior positioning and functioning of components, whether animate or inanimate, that would otherwise be hidden from normal view. Industrial users presently depend upon two-dimensional fluoroscopic systems to perform non-destructive tests upon various types of products. Implementation of stereoscopic visualization could prove useful. The development of a clinical three-dimensional fluoroscope would lend itself to adaptation to these specific needs.

Requests for three-dimensional methods of analysis have stimulated much research in tomography. One development has, in effect, filled a gap for three-dimensional analysis by way of solving another problem for radiologists. Due to its impact upon medical diagnosis, this development deserves comment. Computerized axial tomography is one of the latest developments aimed at differentiating variations in tissue density. EMI Laboratories developed the first clinical system, which is largely based upon analytical methods (12). Quantitative data is generated by passing x-rays through a specific plane of the body. Figure 1 illustrates how this can be done. Twenty-eight thousand eight hundred transmissions are generated by 180 scans; each scan consists of 160 transmission readings. Separation between each
FIG. 1  TOMOGRAPHIC SCAN

1° SEPARATION
BETWEEN EACH SCAN

160 TRANSMISSIONS FOR EACH SCAN

\( \checkmark \) X-RAY SOURCE
\( \checkmark \) X-RAY DETECTOR
scan is 1 degree allowing complete analysis of a transverse section. All 28,800 transmission readings are organized by the computer to form a matrix of absorption values. The output of this computerized analysis can be displayed upon a cathode ray tube or printed out on a printer terminal. This procedure has proved to be a very useful tool to the trained radiologist familiar with this extensive system. Although anatomical definition is very poor, the resolution in the z-direction is sensitive enough to detect the slightest of variations from normal tissue density. Location of abnormalities can be accurately determined because the output is often a large collection of transverse views. Although the information is three-dimensional the output is not stereoscopic. The analysis is not real time and study of kinematical relationships is impossible.

**Early History of Radiology**

The German physicist, Wilhelm Roentgen, initiated the excitement of radiological survey. He accidentally discovered x-rays when he was conducting experiments on the Crooke tube. Roentgen published the first report of his observations on December 28, 1895 (13). This report included a description of an x-ray picture that clearly showed the boney structure of his hand and the ring upon his ring finger. His report aroused the interests of scientists all over the world. Within a month's time the Roentgen x-ray apparatus had become a tool of the physician. This simple piece of equipment quickly found its way into many hospitals and doctor's offices to be used as a diagnostic
and surgical tool. Numerous reports were released describing the uses of these simple setups.

Along with the improvements to the Roentgen x-ray apparatus, developments of a three-dimensional radiograph were underway. Stereoscopic analysis of photographs had been developed by Wheatstone in 1838 (14). Given two photographs of an object from slightly different views, Wheatstone developed the optics to reassemble a three-dimensional picture. In essence, each of the photographs simulated the view perceived by each eye. The photographs were made by simply rotating the camera, between pictures, by an angle of about six degrees. The optical apparatus was then used to limit the vision of each eye to the appropriate photograph. The human brain could then integrate the two two-dimensional pictures into one three-dimensional image. This phenomena is called stereopsis. Early radiologists such as Davidson (1), Gass and Hatchett (15), and Kerekes (16) addressed themselves to the task of implementing this concept to radiography. They achieved stereoradiography by replacing the two photographs with two x-ray films and modifying the optics to accommodate the larger size of the radiographs.

Another method to achieve stereopsis in skiagraphy is best described as the "cross-eyed" system. This particular method of analysis was developed in the late nineteenth century but remains popular among radiologists who use stereoscopic information today. This pseudostereoscope's principle of operation is illustrated in Fig. 2. Stereoscopic vision is obtained by placing the left radiograph
FIG. 2
STEREOSCOPIC OPTICAL APPARATUS
on the right side, the right radiograph on the left side, then crossing the eyes to force convergence upon a point considerably in front of the films. This allows the radiologist to perceive a stereoscopic picture.

By 1930 most radiographs were taken stereoscopically (10). Despite the fact that injuries due to radiation exposure had been released as early as 1896 (17), no one suspected the possible latent effects. After evidence of these effects became apparent, development of stereoscopic equipment was curbed. After the 1950's, electronic technology had advanced so that application of three-dimensional analysis to radiology was again feasible. These developments were concentrated in the area of stereofluoroscopy.

History of Stereofluoroscopy

Fluoroscopy was actually what Roentgen first observed in his laboratory in 1895. Immediate interest was shown in the development of a stereofluoroscopic system. While working on stereoradiographic analysis, J. Machenzie Davidson, obtained a patent, in 1900, for his purposed stereofluoroscopic system (18). He intended to achieve the stereoscopic image by presenting the left fluoroscopic picture and the corresponding right fluoroscopic picture in an alternating fashion. By mechanically synchronizing a shutter to coordinate the vision of the left eye with the left fluoroscopic picture and the right eye with the right fluoroscopic picture, the mind could integrate the different scenes to form a three-dimensional image. A schematic diagram of how
this system might look is shown in Fig. 3.

Two main points that greatly influence a system of this nature should be noted. First, exact synchronization between the two x-rays sources, that produce the fluoroscopic images, and the mechanical shutter would be necessary. Secondly, the frequency of these processes would be required to maintain a minimum critical value. This value would have to be chosen to reduce flicker, eliminate stop action, and allow stereopsis. General figures that have been proposed as guidelines are 50 frames/sec, 15 frames/sec, and 20 frames/sec (19) respectively.

Many systems, similar to Davidson's, had been proposed in the early 1900's. DuMond, in 1932, pointed out that many stereofluoroscopes had been proposed yet none was produced or made available to the medical clientele (2). In the same article he elaborated on the design and development of his stereofluoroscope. Unfortunately, his design did not gain universal acceptance in clinical use.

W. E. Chamberlain, in 1941, made the observation that the fluoroscopic image brightness had to be increased about 1000 times before a suitable stereoscopic fluoroscope could be further developed (20). In 1950, the development of the x-ray image intensifier allowed Chamberlain to use less radiation to achieve the required brightness for stereoscopic analysis. The basic setup consisted of two x-ray sources that were directed toward the front of a 5-inch diameter image intensifier. A low-power stereomicroscope then allowed stereoscopic analysis of the light image at the rear of the intensifier.
Thus, Chamberlain had shown that stereofluoroscopic information could be obtained, but his method of visualization was too restrictive.

The image intensifier's development allowed interfacing with cine recorders for further enhancement of radiological information. Through simple optics, the cine camera can be used to record a fluoroscopic examination. Cinefluoroscopic techniques also can acquire non-real-time stereoscopic effects. Figure 4 presents an illustration of how this can be achieved. Two x-ray sources are used to present two distinct discriminate images. The only other immediate requirement is synchronization between the cine camera's shutter and the switching frequency of the x-ray sources. After development of the film, splicing is performed to make two separate films, each simulating what the individual eye would perceive. Convergent lenses or polarized filters are used to achieve stereopsis. This type of system is not real-time; however, its implementation in stereoscopic analysis shows the tremendous potential that real-time stereofluoroscopic information has in clinical situations (4,8,9,11).

The applications of television technology helped improve the methods of stereoscopic visualization. H. M. Stauffer and his associates applied television technology to give the viewer more freedom than was originally possible with optical methods. Observation and analysis of diagnostic procedures could now be performed aside from the actual radiological examination. Constraints upon the viewers head position were not as restrictive as those imposed by Chamberlain's stereomicroscope. In 1962 Stauffer (21) used two
FIG. 4  STEREO-CINEFLUOROSCOPY
x-ray sources and a 9-inch diameter image intensifier to create alternating discriminate images. Two image Orthicon cameras were used to differentiate the left and right images. Each camera sent its information to the respective left or right video monitor. Polarized glasses and a beam splitter were used to direct each eye's vision to the appropriate monitor. In 1964, Stauffer (6) reported further refinements upon his system. The polarization materials were replaced with red and green filters to better facilitate the stereoscopic visualization system. This still was not enough to improve radiologists' interests.

More recent work was done by Dümmling and Maass (22). The proposed system provides a better visualization system. Two x-ray sources were to be employed to strike a single image intensifier screen as shown in Fig. 5. One camera, however, could detect the image intensifier output, and electronic circuitry could send the appropriate fluoroscopic image to one of two monitors. Prismatic glasses with polarizing filters could enable convergence and discrimination. The glasses were an improvement over previous methods because they incorporated bifocal design. This allowed the physician to perform operative procedures while looking through the lower portion of the lenses. The upper half of the lenses were prismatic to enable stereoscopic analysis of the patient, when desired. At this time they have not developed a real-time fluoroscopic system. They do, however, use a stereo-cinefluoroscopic system for clinical diagnostic purposes.
FIG. 5 DÜMMLING AND MAASS'S PROPOSED SYSTEM

* see ref. 22
Dose Reduction

Several schemes for reducing dose exposure have resulted from the development of the image intensifier. Improvement in the image brightness allowed Chamberlain (20) to see stereo. Even more important, radiation exposures were reduced to achieve better fluoroscopic information than was previously possible. Development of the image intensifier allowed a image to be produced that was bright enough to successfully photograph the image intensifier's output with a cine camera. Several authors (4,23) have described the implementation of cine cameras to fluoroscopy for the purpose of dose reduction. Dose reduction was not immediate. A permanent record was made of the examination and, thus, prevented repeating an examination several times to view the needed information. As previously mentioned, the cine technique was used to evaluate the benefits of stereofluoroscopic information.

Television technology found immediate application to fluoroscopy once the image intensifier had been developed. While offering further enhancement of image brightness and further radiation dose, reduction, television allowed versatile visualization. It would be possible to observe real-time fluoroscopic procedures with the viewer removed from the actual examination. Hospital personnel could be removed from much of the radiation. Television technology introduced other forms of dose reduction. The nature of television's analog output made the addition of electronic storage devices possible.
Clinical fluoroscopes in use today often have video tape recorders, operating in parallel, to record the fluoroscopic examination. The use of such a device, similar to cine, does not necessarily offer dose reduction, but it does provide a method for reviewing an examination repeatedly without further radiation exposure. Several advantages make this system more desirable than cine methods. First, the video tape can be re-used to record fluoroscopic procedures, thereby, reducing the expensive cost of films. Secondly, film development times are not a factor; almost immediate replay is possible.

Another device that has been successfully implemented into fluoroscopic systems is the video disc recorder. Pulsed fluoroscopy using a video disc recorder can offer great reduction in dose exposures. Grollman et al. (24), Zatz et al. (25), and Dorph et al. (26) are some of the researchers who have designed and tested this type of system. They have shown dose reductions between 50 and 90-per cent. Figure 6 shows basically how the system functions. Initial implementation of this system required the combined efforts of several technologies. The first breakthrough was achieved by using grid-pulsed x-ray tubes. By positioning a third electrode between the anode and cathode, short and controlled bursts of radiation were obtained. By applying a negative potential to the third electrode, the flow of electrons towards the anode is prevented. When a fluoroscopic picture is desired, the pulsed x-ray tube is fired causing buildup of the fluoroscopic image on the image-intensifier and television camera. The video disc recorder stores the video signal
as it is being displayed on the television monitor. The video disc recorder is employed because it has the ability to instantaneously replay the video signal until new updated information is required; this simulates a continuous fluoroscopic picture. Substantial savings of radiation exposure can be achieved by updating the information at less frequent rates.

Computerized storage systems may find particular application to fluoroscopy in the future. A computer with sufficient memory could replace the video disc recorder in pulsed fluoroscopic applications. A significant advantage would be the reduced maintenance costs. Existing computers have the ability to digitalize the analog signal and store it on disc or tape. However, state-of-the-art technology has yet to develop a processor that can access a large enough random access memory within the time constraints imposed by the video signal. Some expensive systems are being developed and economical hardware to perform the task of the disc recorder will probably become available in the near future.

Another technology that is finding more applications in fluoroscopic dose reduction is the video storage tube. Storage tubes in the past have had short image retention times. Webster and Smith (27), in 1962, were one of the first to apply this technology to fluoroscopy. They had hopes of producing a stereofluoroscope much like the one proposed by Stauffer and his associates. In their design they incorporated the storage tube to reduce exposure levels. Only recently have improvements been made in technology so that application
to dose reduction in fluoroscopy is feasible. Economical aspects of this type of storage system are attractive. A single video storage tube, with the controlling circuitry, can be purchased for less than five thousand dollars. For the purpose of comparison, a video disc recorder could easily exceed thirty-two thousand dollars.

Stereoscopic Visualization

Many new methods of stereoscopic visualization are currently being investigated (28). The latest development to aid in three-dimensional imaging is the use of electro-optic ceramic crystals and a single television monitor. Two men, Perry and Roese, simultaneously arrived at the idea. These systems are very much the same (28-31). A detailed analysis and description will follow in Chapter 2. Through optimal use of video circuitry they have been able to present a complete stereo image by using only one video monitor. This is important because it eliminates the use of physically restrictive prismatic glasses. As a result of the application of this new technique, the physician would have much more physical freedom and would be capable of performing necessary clinical tasks while benefiting from the use of stereoscopic information. Roese has demonstrated the value of such a visualization system by simulating its use with stereocinefluoroscopic films.

Objectives

A new stereofluoroscopic system, incorporating state-of-the-art technology for image visualization and dose reduction, is to be
developed at Virginia Polytechnic Institute and State University. This thesis documents the author's efforts in this area. Below are the specific thesis objectives:

1) Select the fluoroscopic and video equipment to allow stereofluoroscopic analysis;

2) Design the stereofluoroscopic system to allow minimum radiation exposure;

3) Develop a microcomputer control system to coordinate all stereofluoroscopic operation.
II. PROPOSED THREE-DIMENSIONAL FLUOROSCOPE

Visualization

Conventional Operation of Television

It is necessary to briefly discuss how a standard television works before specific reference is made to stereoscopic applications. Most television systems throughout the world follow the same principles of operation. One difference that distinguishes the various systems is the rate at which the video information is presented to the viewer. In the United States a television broadcast presents thirty frames of video information each second, and each frame ideally consists of about 525 horizontal lines of information. An electron gun at the anode of the monitor presents the video picture by scanning the output screen 525 times every 1/30 of a second. A television camera records the image by scanning the input screen 525 times every 1/30 of a second. The motion of the electron beams for the camera and the monitor follow similar patterns simultaneously. A single synchronization unit is used in many closed circuit applications to power the deflection of the electron beams of both the camera and the monitor.

Flicker can be noticed by the observer if only one picture is shown each 1/30 of a second. To alleviate this, early television engineers decided to show the same picture twice. A complete frame of information is shown each 1/30 of a second by tracing half of it during the first 1/60 of a second and the other half during the
second 1/60 of a second. Each half of a frame is called a field. About 525 lines of information are achieved by showing the odd lines during the first field scan and the even lines during the second field scan. Figure 7 shows how the television's fields are combined to present a single frame of about 525 television lines. Figure 8 illustrates two portions of the basic video waveform. Each of the peaks with a period of 63.5 microseconds is the horizontal retrace signal that causes the electron beam to return to one side of the television screen before each horizontal line of information is displayed. The long series of pulses in (a) and (b) represent the first field's and second field's vertical retrace signals, respectively. They signal the deflection circuitry to position the electron beam at the top of the display screen. This happens just before each field is displayed.

Stereoscopic Visualization

A stereo image is obtained through stereopsis. To achieve stereopsis, two discriminate images must be presented such that each eye perceives only its corresponding view. Perry (29) demonstrated how a stereo image can be presented using special goggles and a single television monitor. One discriminate view is displayed each time a field is scanned. Therefore, a complete stereoscopic picture is presented every 1/30 of a second. In this fluoroscopic application, the two discriminate fluoroscopic pictures will be presented to a single television camera in an alternating sequence. The camera
\[ \text{time} = \frac{1}{30} \text{ sec} \]

\[ \text{time} = \frac{1}{60} \text{ sec} \]

\[ \text{time} = \frac{1}{60} \text{ sec} \]

\[ \begin{array}{c}
\text{TV LINE} \\
1 \\
2 \\
3 \\
4 \\
5 \\
\vdots \\
522 \\
523 \\
524 \\
525 \\
\text{TOTAL FRAME}
\end{array} \]

\[ \begin{array}{c}
\text{TV LINE} \\
1 \\
2 \\
3 \\
5 \\
\vdots \\
523 \\
525 \\
\text{FIRST FIELD}
\end{array} \]

\[ \begin{array}{c}
\text{TV LINE} \\
2 \\
4 \\
\vdots \\
522 \\
524 \\
\text{SECOND FIELD}
\end{array} \]

**ONE FRAME = ONE FIRST FIELD + ONE SECOND FIELD**

**FIG. 7 A FRAME CONSISTS OF TWO FIELDS**
translates each picture into an analog output signal that is relayed to the television monitor. Use of goggles allows stereopsis. Without the goggles, the three-dimensional information would be lost and only a double image would be viewed by both eyes.

The goggles work in part with a polarized plate to shutter light to each eye. The goggles are two electro-optic ceramic plates made of lead, lanthanum, zirconate, and titanate (PLZT). Each lens can act as a polarized plate when an electric potential is placed across it. Total cancellation of light is achieved by orienting the polarization axes of the PLZT crystals and the initial polarization plate 90 degrees apart. Figure 9 shows schematically how the initial polarization plate and the goggles are used to provide stereopsis. The PLZT crystals are synchronized by the vertical retrace signal to permit the left eye to perceive the first field and the right eye to perceive the second field.

As stated in Chapter 1, both Perry and Roese developed similar systems. However, a difference does exist. Figure 9 shows the initial polarizer placed to the surface of the video monitor. This is how Perry's system was designed. Roese placed the initial polarizer at the surface of the crystals. Perry's system seemed superior in that ambient lighting conditions were not attenuated by the initial polarizer. The physician could perform clinical tasks with less cancellation of the surrounding's light intensity. On the other hand, Roese's goggles allowed complete freedom of rotation in the observer's coronal plane. The author's system will be designed to
incorporate Perry's design. If Perry's method of visualization proves to be physically restrictive within the coronal plane, a mechanism could be installed to rotate the initial polarizer in a direct relationship to the observer's head orientation.

Fluoroscopic and Video Equipment

The visualization system described above has been extensively tested in non-fluoroscopic applications by using two television cameras to obtain two discriminate images. Furthermore, the visualization system has been tested with stereo-cinefluoroscopic films to study the feasibility of its application to fluoroscopy. Applying this technology to real-time analysis requires that some adjustments be made to existing fluoroscopic equipment. All successful stereoscopic applications to fluoroscopy have been achieved by using two x-ray sources and a single image intensifier. A similar system is proposed here as is illustrated in Fig. 10.

Two grid pulsed x-ray sources will be used so that precise control over x-ray exposure is obtainable. The focal points of these two tubes will be pointed directly to the center of the image intensifier's input screen. The large size of the x-ray sources may require that they be placed in a staggered position in order that small angles of separation may be obtained. When the x-ray source is fired, the x-rays will penetrate the body tissues and impose an x-ray differentiation pattern upon the image intensifier's screen. The radiologist has control over the x-ray tube's voltage and current. The x-ray sources
FIG. 10  FLUOROSCOPIC SYSTEM ADAPTED TO STEREO
will be designed to be turned on and turned off with digital electronic pulses so that variable pulse lengths of x-ray radiation will be obtainable.

Special consideration will be given to select an image intensifier and a video camera that can successfully receive and transmit the fluoroscopic information. A conventional image intensifier can be used provided its buildup and decay times accommodate the update frequency. The maximum rate that each x-ray tube will be fired is 60 Hz. The image intensifier must be able to conform to this constraint. The response of the image intensifier will not be as important as the response of the camera. The nature of the camera's target permits some storage capability. Therefore, the image intensifier must only present the camera with an instantaneous light image. The camera's target acts as a light integrater and each portion of the target area essentially retains its charge until the electron beam traces and discharges that portion of the screen. For this reason, it is of vital importance that the camera be able to build up a charged pattern very quickly and then hold that information for the time required to scan one video field. Appendix C discusses the selection of the video camera and the image intensifier in more specific detail.

Figure 11 summarizes the basic timing constraints that are imposed upon each component of the fluoroscopic system. This specific illustration presumes that no consideration is given to dose reduction, and that the system is operating at its maximum
FIG. 11  STEREOSERUOROSCOPIE TIMING
update rate. This figure does not represent an existing system's operation, but it yields a general idea of how the two x-ray sources, the image intensifier, and the television camera work together to provide a stereoscopic image.

Dose Reduction

System Operation

Substantial savings in radiation exposure to the patient and hospital personnel can be achieved by updating the information only when absolutely necessary. A fluoroscopic system must have the ability to present new information at rates fast enough to observe kinematic relationships. On the other hand, should the physician be interested in instantaneous static views, reduction in radiation exposure can be achieved by re-displaying a recorded image. The video storage tube makes the continuous replay of stereoscopic information possible. Reduction of dose is obtained when update rates are less than thirty frames a second; this requires that the initial video information be stored by the storage tubes so that replay is possible.

Figure 12 shows the entire fluoroscopic system and the basic components required to allow dose reduction. The fluoroscopic system is identical to that previously described. The dose reduction system will be composed of one 8080 microcomputer and two Hughes Aircraft Scan-Converters. The computer synchronizes the fluoroscopic equipment, the storage tubes, and the video system. The computer
precisely rations the exposure of radiation according to the update rate input by the radiologist. The value of using a sophisticated computer as a controller is the versatility that the system has to incorporate a wide range of operational parameters. A wide range of update rates allows adaptation of the fluoroscopic system to a wide range of clinical situations while providing the maximum dose reduction.

Regardless of the update rate, the initial fluoroscopic image is always recorded by one of the storage tubes. Two storage tubes are required so that continuous visualization is available. One of the storage tubes is always in the process of being erased so that it can be ready to record the next frame of information. The computer keeps track of which storage tube has the stored fluoroscopic information and which storage tube is ready to record the next fluoroscopic information. Switching circuitry is manipulated by the computer to channel the video signal between the camera, storage tubes, and monitor. One main characteristic of this dose reduction system is the continuous display of the fluoroscopic image. This is possible because the storage tube has the ability to switch from the write mode to the read mode of operation within the time it takes for video vertical retrace. It is possible to display a maximum of 30 frames of stereofluoroscopic information each second. This allows no reduction in exposure, but real-time kinematic analysis is possible. Figure 13 shows how the system works at this maximum update rate. The x-ray sources are pulsed at the beginning of each vertical retrace
FIG. 13  STEREOSCOPY (30 frames/sec)
signal in an alternating sequence. The fluoroscopic images build up on the image intensifier and are recorded by the television camera. Since the image is not to be redisplayed, no reduction in radiation exposure is possible.

Less frequent update rates provide dose reduction, but a loss of time-dependent information is incurred. Figure 14 illustrates the computer's control over the fluoroscopic components for a specific update rate of 15 frames per second. Once the initial stereofluoroscopic information has been recorded by the storage tube, the computer signals it to redisplay the recorded information. Changes in the storage tube's mode of operation occur immediately after the first field vertical retrace signal is initiated. It is important to note that regardless of update rate, stored video information is always being replayed if a fluoroscopic image is not being rejuvenated.

**Scan-Converter**

Since the storage tube is the electronic component that will allow dose reduction, the following description is included that specifically describes how the storage tube works. Figure 15 is a diagram of the storage tube. Figure 15 (a) displays the main components that are required for the storage tube's operation. Supporting circuitry is purchased to control the operation of these

---

*Information acquired through personal conversation with Gerald M. Fox and sales literature from Hughes Aircraft Company.*
FIG. 14  STEREOSCOPY (15 frames/sec)
components. The storage tube is almost identical to any high quality video display tube. The difference lies in the storage target. Rather than emitting a light image, as is the case with a video display tube, the storage tube acts as if it were a collection of thousands of small capacitors. They are charged by the electron beam according to the amplitude of the video signal. During the replay operation, the electron beam is influenced by the charged pattern as it scans the storage surface. This allows the video signal to be replicated. The electron gun performs the same scanning sequence as does the camera and monitor. All are controlled by the same synchronization unit. Control of writing, reading, and erasing, i.e., destructive reading, is a consequence of the voltage potential applied across the storage target and control grid. The scan converter has the ability to retain an image for about one hour.
III. CONTROLLING SYSTEM

The 8080 Microcomputer

The specific computer used in this simulation is the E & L Instruments, Inc. Micro Designer® microcomputer. The processor chip employed is an Intel 8080. The microcomputer was selected as the controlling mechanism over standard truth table logic systems (TTL) for several reasons.

An extensive TTL system would be required to control the basic stereofluoroscopic system. The control system would steadily increase in complexity as dose control options are added. Trouble is often manifest in such large hardware designs because all components must be simultaneously coordinated to achieve proper operation. In addition, component failure has a greater chance of occurring in these large circuits. A microcomputer can provide complete control with less hardware. Basic standard hardware design is used to transfer information to and from the computer while the software manipulates and directs all operations.

The versatility of the computer is largely due to software. The computer possesses the ability to regulate a mechanism based upon large and diverse quantities of input information. Once the influencing factors have been translated into computer language, it is up to the software to make the appropriate decisions. Substantial

*Micro Designer® is a registered trademark of E & L Instruments, Inc.
advantages can be attained from substituting software for hardware. Design and modification of software systems is relatively easy. Extensive systems like MAC80 (a cross-assembler for the Intel 8080) and INTERP/80 (a simulator for the Intel 8080) have been developed to aid with design and adaptation of computer programs to the microcomputer.

Hardware is the key element of TTL logic systems. For this reason design changes will always require hardware modification. Even simple design changes can prove to be unwieldy undertakings. The computer requires hardware. However, computer hardware has dropped in price to the point that substitution of software for hardware becomes very attractive. The cost of computer hardware already competes with the cost of larger TTL systems. Computer costs are expected to drop even further as production and use increase.

Specific operational characteristics of an 8080-based microcomputer certainly make it an excellent controller for this fluoroscopic system. The microcomputer is fast enough for control applications of this nature. A single 8080 instruction takes from four to eight machine cycles to complete. This is equivalent to two to nine microseconds (μs) if the internal clock operates at its full speed of 2 MHz. As an example, in the time it takes for one field of video information to be displayed (1/60 second, or 16.67 milliseconds) the computer can complete at least 1,800 eighteen cycle operations. This is many more instructions than required to control the fluoroscope. The 8080 is also an eight-bit device. Being an eight-bit device, the instruction set is powerful enough to perform extensive control and computational
procedures. The computer has the ability to communicate eight bits of information during any one input or output operation. With these timing and communication constraints in mind, a controller for the fluoroscope was developed.

Development of a computer system like this is quite an involved process because the hardware and software must be incorporated to complement each other's needs. Several references proved helpful in explaining the interaction between these systems. An exceptional reference for explaining basic computer operation and interfacing is The Bugbook III, Microcomputer Interfacing by Rony, Larsen, and Titus (32). A useful reference for a detailed description of the 8080 instruction set is the Intel 8080 Assembly Language Programming Manual (33). The software and hardware both are responsible for the interaction between the computer and the fluoroscope.

**Software and Hardware**

**Basic Operation**

The controller system will synchronize the operation of two x-ray sources, two storage tubes, the goggles, and the video system. The radiologist will input control information that directly influences how the computer controls the fluoroscopic system. All control is derived from the computer-generated output, which is a function of internal and external parameters. The software system manipulates computer operations to digest input and generate output. The interfacing system manipulates and regulates all of the electronic
information that flows to and from the computer. Both the hardware and the software make mutual contributions to the control of the fluoroscope and its supporting equipment. Due to this close interdependence, both the hardware and the software had to be designed simultaneously.

The entire software program was developed using the MAC80 Cross Assembler, as it is provided by the Virginia Tech Conversational Monitor System. This is particularly useful because the program is initially set up using mnemonic codes as established by Intel (33). When compiled, MAC80 helped debug the program. A hexadecimal code representing each memory location and its corresponding operational code was assigned by the assembler. For a complete listing of the computer program refer to Appendix A. The 8080 machine code was input into the Micro Designer by using this MAC80 computer output directly.

Unlike the software, no particular aids were available to help with the hardware design. The Bugbook III provided some basic circuit diagrams that helped in the initial planning of the basic interfacing chips. A complete breadboard interfacing circuit was developed and tested before the final wire wrap circuit board was produced.

It is necessary to develop the overall function of the computer before the significance of each circuit and operation can be appreciated. Figures 16-22 are the flowcharts that illustrate all of the control functions. Of these procedures, the first is the initialization actions.
FIG. 16 INITIALIZATION ROUTINE
WRITE: HI 00H
LO 18H

interrupt
jam in 337Q

output
It. x-ray pulse

output
It. PLZT pulse

input width
of x-ray pulse

timing loop

output
It. x-ray pulse

input
mode

3-D

check
mode

output
interrupt
status

enable interrupt
return

2-D

output
interrupt
status

enable interrupt
return

FIG. 17 FIRST FIELD WRITE
SUBROUTINE
FIG. 18 SECOND FIELD WRITE SUBROUTINES
FIG. 19  READ INTERRUPT SERVICE SUBROUTINES
FIG. 20  UPDAT SUBROUTINE
FIG. 21  PART OF UPDAT SUBROUTINE
FIG. 22  READ AND WRITE PORTIONS OF THE UPDAT SUBROUTINE
Figure 16 shows the initialization procedure used to set up all internal computer variables and the interfacing hardware. Once this portion of the program has been completed, the controller is ready to regulate the fluoroscopic equipment according to the radiologist's needs. Page 118 of Appendix A shows the portion of the computer program that performs this initialization. For a description of how the computer is manipulated to begin this procedure, refer to the Operator's Manual in Appendix B. This start-up procedure is the only portion of the control program that is not initiated by an interrupt signal.

An interrupt procedure allows a device to request the computer's attention. In this fluoroscopic application, the video synchronization unit will serve as the interrupting device. When the synchronization unit outputs a vertical retrace signal, the computer is interrupted. After the computer acknowledges the interrupt signal and during the next machine cycle, the computer receives an eight-bit instruction that directs subsequent operations. In this application, the interrupt is used to call one of five interrupt service subroutines. Figures 17-22 are the flow charts that illustrate the operations performed by these subroutines.

For the convenience of the reader, Table 1 has been constructed to help reference the specific interrupt service subroutines, shown in Figs. 17-22, with the MAC80 computer output shown in Appendix A. The main point to be conveyed here is that these are five separate subroutines, one of which is used to control the fluoroscope each time the video synchronization unit requests interrupt servicing.
### Table 1. Reference of MAC80 Software

<table>
<thead>
<tr>
<th>Interrupt Servicing Subroutine</th>
<th>Flowchart Figure Number</th>
<th>Appendix A Page Number For MAC80 Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Field Write</td>
<td>17</td>
<td>119-120</td>
</tr>
<tr>
<td>Second Field Write* (3-D Analysis)</td>
<td>Top Half of 18</td>
<td>121-123</td>
</tr>
<tr>
<td>Second Field Write* (2-D Analysis)</td>
<td>Bottom Half of 18</td>
<td>124-125</td>
</tr>
<tr>
<td>First Field Read</td>
<td>Top Half of 19</td>
<td>126</td>
</tr>
<tr>
<td>Second Field Read*</td>
<td>Bottom Half of 19</td>
<td>127-128</td>
</tr>
</tbody>
</table>

*Continuation of all Second Field Interrupt Servicing Subroutines (UPDAT Subroutine) 20-22 129-132
Contained within each interrupt subroutine is a procedure for determining which subroutine is to be used when the computer is interrupted next. This is entirely based upon the instructions given by the radiologist. When the computer is not specifically performing an interrupt service subroutine, it waits for the next interrupt request in the wait loop or an optional program shown in Fig. 16.

One particular feature of this control program is the easy addition of an optional computer program. For example, should it be desirable to determine the radiation exposure to the patient, a program could be added to either sample some external instrumentation or solve a mathematical relationship. Any subroutine will work provided it does not require interrupt servicing. The interrupt servicing has been reserved for fluoroscopic control purposes; controlling the fluoroscope is the computer's top priority. For instructions on how to input an optional program refer to Appendix B. At present, the fluoroscopic control program uses a maximum of 7 milliseconds (msec) during any one field (16.67 msec). This leaves at least 9 msec between successive vertical retrace signals for other non-control tasks. That means that well over 50% of the computer's time can be spent doing other things.

Device Select Pulses

The computer and its interfacing require some means of communicating with each other. Device select pulses are generated to signal the electronic circuits when the computer is ready to output or input
information. Figure 23 is the schematic diagram of how the input
device select pulses are produced. Whenever binary information is
to be input to the computer one of these device select pulses strobe
the tri-state hardware to allow the transfer of data to the computer's
accumulator. Figure 24 shows how the output device select pulses are
made. These pulses strobe external hardware that is to receive data
from the computer's accumulator. The labels that are used to identify
these device select pulses are listed along with the software shown
in Appendix A.

Interrupts

As mentioned before, the computer's control over the fluoroscopic
equipment is entirely the result of interrupt subroutine servicing.
The video synchronization unit controls the video camera, video
monitor, and the storage tubes. The video synchronization unit is
used as the interrupting device because it can serve as a single
common timing unit for the entire fluoroscopic system.

Two different interrupt signals should be generated to insure
that the first field vertical retrace signal initiates the actions
required to produce the first video field of information, and that
the second field vertical retrace signal starts whatever is required
to produce the second field of video information. Figure 25 shows
the electronic circuits that have been designed to distinguish the
two signals' priority in interrupting the computer. The interrupting
pulses should have a duration of 10 to 20 µ sec. The actual sequence
FIG. 23    GENERATION OF INPUT
DEVICE SELECT PULSES
FIG. 24 GENERATION OF OUTPUT DEVICE SELECT PULSES
of pulses provided by the video synchronization unit is at least 1.08 msec long. For that reason, a single-shot multivibrator with the proper timing resistance and capacitance could be used to achieve the appropriate interrupting pulse.

Once the computer is interrupted, an eight-bit instruction must be input into the 8080's accumulator to call the appropriate interrupt service subroutine. A rather complicated system for providing this has been developed. During the preceding servicing of an interrupt, the computer determines which interrupt subroutine is to be executed next. This decision is based upon parameters input by the radiologist. At that time one of five eight-bit binary codes is output and latched by the 74100 chip as shown in Fig. 26. The five codes each represent a machine instruction as follows:

\[317_8\]  
* call subroutine at memory address Hi 000\_8 Lo 010\_8  
(First Field Read Subroutine);

\[327_8\]  
call subroutine at memory address Hi 000\_8 Lo 020\_8  
(Second Field Read Subroutine);

\[337_8\]  
call subroutine at memory address Hi 000\_8 Lo 030\_8  
(First Field Write Subroutine);

\[347_8\]  
call subroutine at memory address Hi 000\_8 Lo 040\_8  
(Second Field Write Subroutine, 2-D);

\[357_8\]  
call subroutine at memory address Hi 000\_8 Lo 050\_8  
(Second Field Write Subroutine, 3-D).

*The subscripted 8 denotes that the binary computer number is represented here as an octal number.
When the computer is interrupted by one of the vertical retrace signals, it strobes the 8212 chip with an interrupt acknowledge pulse to input the machine code latched by the 74100 chip. Figure 26 shows the complete interface circuit used to designate interrupt servicing.

**Inputs**

**GO**

The computer follows a specific control procedure to update the fluoroscopic information only if an appropriate GO command is input to the computer. Essentially, any operation that requires the release of radiation must be specifically enacted by the radiologist depressing either the control panel GO switch or the foot switch. Releasing the switch stops all updating of the fluoroscopic information. The computer associates a GO command with the input of an eight-bit binary number identically equal to zero. Figures 27 and 28 show the hardware used to input this command. If the fluoroscopic system is not updating the image i.e., the GO command is not given, the storage tubes will replay the stored video image.

**MODE**

Figure 28 also shows the interfacing necessary to input the mode selection code. The purpose of the mode selection is to allow use of the fluoroscope's control system in either two-dimensional (conventional) and/or three-dimensional applications. Input of a binary three causes the computer to operate in the three-dimensional mode.
FIG. 27   GO INSTRUCTION INTERFACING
FIG. 28  INPUT OF GO OR MODE
Therefore, both x-ray sources are energized to create two discriminate images. If a binary two is input, the computer operates the fluoroscope so that a two-dimensional image is presented to the viewer. The fluoroscopic control system, presented and tested by the author, pulses the left x-ray source only once when in the two-dimensional mode. Appendix A shows the appropriate software required to pulse the left x-ray source twice, i.e., once during the first field and again during the second field. Selection of the appropriate software system should be based upon the response times of the image intensifier and the video camera.

**UPDATE RATE**

The update rate is selected by the radiologist. By turning a rotary switch to one of eight possible positions, a single eight-bit binary code is input to the computer. The input variable determines the number of times that an image is redisplayed before being updated. The software associates the input variable with a binary counter limit. When the number of times that a fluoroscopic image is redisplayed equals the counter limit, the fluoroscopic information is renewed. Table 2 shows the rotary switch's input to the computer and the associated binary counter limit represented by each position. Figures 29 and 30 show the circuitry required to input the update rate.
Table 2. Update Rate Variables

<table>
<thead>
<tr>
<th>Rotary Switch (Frames/Second)</th>
<th>Binary Input</th>
<th>Binary Counter Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>00000001</td>
<td>None</td>
</tr>
<tr>
<td>0.3</td>
<td>00000010</td>
<td>01100011</td>
</tr>
<tr>
<td>0.5</td>
<td>00000100</td>
<td>00111011</td>
</tr>
<tr>
<td>1.0</td>
<td>00001000</td>
<td>00011101</td>
</tr>
<tr>
<td>2.0</td>
<td>00010000</td>
<td>00001110</td>
</tr>
<tr>
<td>5.0</td>
<td>00100000</td>
<td>00000101</td>
</tr>
<tr>
<td>15.0</td>
<td>01000000</td>
<td>00000001</td>
</tr>
<tr>
<td>30.0</td>
<td>10000000</td>
<td>00000000</td>
</tr>
</tbody>
</table>
FIG. 29  CIRCUIT TO INPUT UPDATE RATE
FIG. 30 UPDATE RATE ROTARY SWITCH

- 2 POLE, 8 POSITION ROTARY SWITCH
- NON-SHORTING
- 0.5V
- GND

UPDATE RATE (frames/sec)

- MANUAL

0.3
0.5
1.0
2.0
5.0
15.0
30.0
PULSE WIDTH

The radiologist has limited control over the pulse width of the x-ray sources. The software is designed such that pulse widths between 0.1 and 6.475 msec can be attained by inputting an appropriate binary variable. The binary number determines how many times the computer is to perform a looping operation before turning the x-ray source off again. A simple relationship is given below to determine the pulse width:

\[
PULSE \text{ WIDTH} = \frac{1}{10} (1 + \frac{1}{4} \text{ HLONG}) \frac{d}{\text{msec}},\]

where HLONG is a decimal number between 0 and 255. The binary number input into the computer is the binary equivalent of HLONG. Figure 31 illustrates the hardware required to transfer this binary number into the computer. Figures 32 and 33 show the hardware used to select specific pulse widths of 0.1, 0.5, 1.5, 2.0, 4.0, or 6.0 msec. The circuits shown in Figs. 31 and 32 are located within the control panel.

Outputs

STORAGE TUBE CONTROL

Complete control of the video storage tubes and the switching circuitry is a function of eight binary bits of information. The controlling information must be ready to be input to the storage tubes and the switching circuitry at the very beginning of the first
FIG. 31 CIRCUIT TO INPUT PULSE WIDTH
FIG. 32 CONTROL PANEL CIRCUIT FOR PULSE WIDTH
FIG. 33  PULSE WIDTH ROTARY SWITCH
field vertical retrace pulse. The control byte influences the operation of the storage tubes for a complete video frame thereafter. Since the timing constraints are so critical, the control information is output by the computer during the second field's interrupt servicing. This makes the control instructions available to the storage tube's control circuits when they need them. Below are the instruction codes output by the computer:

\begin{verbatim}
11000001_2  \text{* causes the first storage tube to record the }
            \text{fluoroscopic information, and the second storage }
            \text{tube to erase all previously stored information; }
\end{verbatim}

\begin{verbatim}
00011100_2  \text{causes the second storage tube to record the }
            \text{fluoroscopic information, and the first storage }
            \text{tube to erase all previously stored information; }
\end{verbatim}

\begin{verbatim}
10100001_2  \text{causes the first storage tube to replay the stored }
            \text{fluoroscopic information, and the second storage }
            \text{tube to continue erasing; }
\end{verbatim}

\begin{verbatim}
00011101_2  \text{causes the second storage tube to replay the stored }
            \text{fluoroscopic information, and the first storage }
            \text{tube to continue erasing. }
\end{verbatim}

Figure 34 gives an idea of how the binary control information is used to control the storage system. Figure 35 illustrates the interfacing used to hold the control information when it is output by the

\*The subscripted 2 denotes that this is a binary number.
FIG. 34 BASIC DIAGRAM OF STORAGE CHAIN
FIG. 35

GENERATION OF STORAGE TUBE CONTROL
computer. Supporting circuitry may be required to interface this output to the specific storage tubes or the switching circuitry.

GOOGLE CONTROLS

Two google pulses are output by the computer to synchronize the goggles with the appropriate video field. The computer always synchronizes the goggles irrespective of update rate or mode of operation. This allows the physician to keep the goggles on even if he is operating the fluoroscope in the two-dimensional mode. In Fig. 24, the pulses labeled LTG and RTG are used to synchronize the goggles. The pulses are negative going pulses that have a duration of 500 nanoseconds (nsec).

X-RAY CONTROLS

The grid pulsed x-ray sources will be switched on and off with TTL logic. The operation of each source will be turned on by one pulse and turned off by another. Figure 24 shows the device select pulses labeled LXO and LXOFF. They are used to turn the left x-ray tube on and off respectively. Similarly, the RXO and RXOFF pulses turn the right x-ray source on and off. The pulses are negative going pulses 500 nsec long.

Other Interfacing Circuits

SIGNAL LIGHT

Figure 36 shows the circuit used to signal the radiologist when
FIG. 36 CIRCUIT FOR CONTROL PANEL LIGHT
x-rays are being emitted. The light is mounted to the control panel and flashes each time the x-ray sources are pulsed on by the computer. The transistor circuit is located within the control panel.

POWER-UP RESET

A simple circuit is added to the interfacing board to initiate all computer operation the moment the radiologist turns controller on. Figure 37 shows the monostable multivibrator that is adapted to this use. The R-C circuit tied to the schmitt-trigger input causes a delayed input pulse to restart the computer.

Control Hardware

All of the interfacing circuits have been prepared for maximum ease of operation. The interfacing circuits that will not be modified by future users have been mounted on an interfacing circuit board and wirewrapped. Figure 38 shows the interfacing board and the location of the integrated circuit chips. Three sockets have been located in the upper right hand corner to provide all input and output to the computer controller. Figure 39 shows the sockets in more detail. Pin locations are labeled according to the variable names used to describe the interfacing circuits. For a detailed description of the inputs and outputs refer to the operator's manual in Appendix B.

The inputs to the computer controller are provided by either the control panel or the foot switch. Figure 40 shows the controls provided by the control panel. The foot switch simply provides an
FIG. 37 POWER-UP RESET
FIG. 38  INTERFACING BOARD
FIG. 39 INTERFACE BOARD SOCKETS
extra means for the radiologist to input the GO instruction.
IV. TESTS AND RESULTS

Single-Step Testing

By placing the computer in the single-step mode of operation, detailed analysis of the computer's functions could be achieved. Single stepping allowed the computer to complete one machine cycle at a time. During that time all electronic signals in the computer and the interfacing could be carefully evaluated. Operation would be identical to full speed computer operation except that processes occur under the complete discretion of the operator. Debugging of both hardware and software systems were completed in this manner.

Figure 41 shows the switches that were manipulated to place the Micro Designer® in the single-step mode. The following procedure was followed.

a) All of the data toggle switches were placed in the up position. This was required to allow the computer to input information to the accumulator.

b) The HI, LO, DEP, and EXAM toggle switches were checked to see that they had returned to their normal up position.

c) Toggling the HOLD switch up suspended all operation.

d) Two STEP switches are on the control panel of the computer; the metallic switch remained in its normal down position but the yellow STEP switch was flipped up for single step control.

e) With the right hand, the metallic RESET switch was held up
FIG. 41 MICRO DESIGNER CONTROL PANEL
and the blue HOLD switch was simultaneously flipped down.

After this, the RESET switch could be released.

If the above procedures were correctly followed the computer would be set at memory location HI 00000002 and LO 00000002 and ready to execute the program. The binary number 110000112 would be displayed on the computer control panel's data bus monitors. This machine code would represent the first operation that the computer had to complete. It would be the exact hexadecimal machine code C3 shown to be at memory location HI 00H* and LO 00H by the MAC80 output (refer to Appendix A).

By depressing the metallic STEP switch once, the computer could be advanced one machine cycle. The entire program could be performed by toggling through each operation. Although this would be a rather tedious process, it was one way of checking each operation of the computer. Whenever it was desirable to start the program back at the beginning, this could be done while in the single step mode by momentarily pushing the RESET switch up.

Modeling the Input Signals

Several changes were made to facilitate easy testing during single step operation. The GO switch to be used in the clinical

* The H that follows the two numbers represents hexadecimal notation of the eight-bit HI memory address, the eight-bit LO memory address, or the eight-bit machine code.
system would be a momentary contact SPDT pushbutton type. This was employed so that the radiologist had to continually push the switch to achieve the radiation exposure required for fluoroscopic updating. When testing the computer's operation in this non-clinical situation it was advantageous to replace the push button with a SPDT slide switch. This way the GO instruction could be given continuously while other manipulations were made. This adaptation was easily performed by replacing the wires that ran from the GO switch on the control panel with wires than ran to a SPDT slide switch. Appendix B gives complete details of how the control panel wires were connected.

A method was also provided to simulate the interrupting signals of the video synchronization unit. The usual interrupt pulse would be a 60 Hz signal, but for single step testing it was beneficial to interrupt the computer manually. Two SPDT slide switches were used to provide these signals. Appendix B provides information on how the interrupt signals would be applied to the interfacing board.

**Monitoring Output Signals**

Light emitting diodes (LEDs) could be connected to the computer busses to check logic states. Figure 42 shows a transistor circuit used to make the LED logic probes. Six of these circuits were used to monitor the output of the interfacing board sockets. Figure 39 shows the location of the following outputs that were monitored:
FIG. 42 CIRCUIT USED FOR LOGIC MONITORS

* Circuit taken from page 6-10 of the Bugbook II by Rony and Larsen, E&L Instruments, Inc., Derby, Connecticut 06418.
LXO...... pulse to turn the left x-ray source on,
LXOFF..... pulse to turn the left x-ray source off,
RXO...... pulse to turn the right x-ray source on,
RXOFF..... pulse to turn the right x-ray source off,
LTG...... pulse to signal the left goggle,
RTG...... pulse to signal the right goggle.

All of the above outputs were negative going pulses. For that reason the LEDs were normally lit. An output signal turned the LED monitor off.

**Tests Conducted**

Single-step testing was used to determine if the computer was functioning correctly. Correct operation could not be inferred from any one of the tests shown below. The best test is not discussed here because it involved sitting down with the MAC80 output shown in Appendix A and single-stepping through every operation. Logic probes were used to test the logic states of all electronic hardware. The tests shown below were used as quick checks to see that the computer was interrupted correctly. All five interrupt service subroutines could be observed.

**TEST 1 READ INTERRUPT SERVICING**

This test demonstrated that the computer could be interrupted properly and that it could access the interrupt service subroutines necessary to replay a stored fluoroscopic image. Analysis of the
MAC80 program shows that two interrupt subroutines must be performed; the first begins at memory address OOH HI and O8H LO, and the second begins at memory address OOH HI and 10H LO. The following test was performed to demonstrate this.

The test was begun by setting up the computer so that it could acknowledge an interrupt request. The computer was ready when it had entered the wait loop shown in Fig. 16. It was necessary to arrive at this point by performing the initialization procedure shown in Fig. 16 because the computer was just put in the single step mode. The computer could be advanced to the wait loop by one of two methods. First, the metallic STEP switch could be toggled to step through the entire routine. Secondly, the computer could be temporarily placed in full speed operation by positioning the yellow STEP switch down for a few seconds. Full speed operation eliminated toggling time but the intermediate functions of the computer went unnoticed. When the computer returned to single step operation the computer was in the process of performing one of the operations in the wait loop. In either case, the controller was ready to receive an interrupt.

Interrupting the computer was achieved by switching the first field interrupt switch to a logic 1 and toggling the computer until the INTE light on the Micro Designer control panel went off. After turning the interrupt signal off, the computer was advanced three more machine cycles. At that point the interrupt had been completed and the LED monitors on the control panel displayed HI 00000002, LO 000010002, and MD 110000112. This meant that the computer was
ready to perform the first field interrupt servicing subroutine. The computer had been successfully interrupted at that point.

To test for the next interrupt, the computer was advanced to the wait loop again. At that time the computer was interrupted by turning the second field interrupt slide switch on, toggling the computer until the INTE light went off, and then turning the interrupt switch off. After toggling three more machine cycles the Micro Designer control panel displayed HI 00000002, LO 000100002, and MD 110000112. This meant that the computer had successfully begun the second field read interrupt service subroutine.

TEST 2 THREE-DIMENSIONAL WRITE INTERRUPT SERVICING

This test checked the computer's ability to perform the interrupting service subroutines to achieve three-dimensional control of the fluoroscope. Successful operation would be performed if the two interrupt signals call subroutines at 00H HI 18H LO and 00H HI 28H LO in that order. This could be confirmed by consulting the MAC80 program.

Before proceeding, the following control information was selected on the fluoroscopic control panel. The 3-D mode of operation and an update rate of 30 frames/second were set. A pulse width of 0.1 msec was selected; this saved toggling through a long timing loop. The GO slide switch was turned on.

To allow the computer to input the information, one entire second field interrupt service subroutine had to be completed. To ensure that
this had been done, the following operations were performed: 1) set
the yellow STEP switch in its up position; 2) place the computer in full
speed operation, 3) momentarily turn the first field interrupt switch
on; 4) momentarily turn the second interrupt switch on; 5) set the
computer back to the single step mode. All of the information had
been input and the controller was ready to be interrupted.

The first field interrupt procedure, as described in Test 1, was
performed. The Micro Designer control panel displayed HI 00000000₂,
LO 00011000₂, and MD 11010011₂. This represented the first memory
location for the first field write interrupt service subroutine. The
computer had received the appropriate control information and in-
terrupt signals to begin the updating procedure.

After advancing operation to the wait loop, the computer was
ready to receive the second field interrupt request. Upon a success-
ful interrupt, the control panel displayed HI 00000000₂, LO 00101000₂,
and MD 11010011₂. This was the appropriate display since the computer
was beginning the second field write interrupt service subroutine
for three-dimensional analysis.

TEST 3 TWO-DIMENSIONAL WRITE INTERRUPT SERVICING

This test demonstrated that the controlling mechanism could adapt
to two-dimensional analysis. The MAC80 output shows that if the
computer is properly interrupted, the first field servicing begins at
HI 00H Lo 18H. This proved to be the same as for three-dimensional
analysis. The difference was that for second field servicing,
memory location HI 00H LO 20H would be the memory location for the first instruction of that service subroutine.

Except for the MODE control, all of the settings remained the same as they were in Test 2. MODE was toggled to the 2-D position. The test procedure outlined in Test 2 was performed. The only difference to be observed was in the second field interrupt servicing. The computer control panel displayed HI 00000000₂, LO 00100000₂, and MD 11000011₂ to demonstrate that the computer had begun the second field write interrupt service subroutine for two-dimensional analysis.

TEST 4 INTERRUPT PRIORITY

The priority circuit used to control the interrupting of the computer was tested here. The test was set up just to acknowledge that only the appropriate interrupt signal would initiate the response of the computer.

To begin, the computer was restarted and re-initialized as in Test 1. When the computer was ready to receive its first interrupt, the second field interrupt signal was tried but it received no response. The computer could advance to the interrupt service subroutine only when it was interrupted by the first field interrupt signal. After that subroutine had been completed, the system expected the second field interrupt. The first field interrupt signal could not generate a computer response. Only the second field signal initiated computer action. At that point it was apparent that only
the first field interrupt signal initiated the first field of video information to be produced. In similar manner, the second field interrupt could only initiate the second field of video information.

**Full Speed Testing**

Full speed testing was most valuable because the functions of the computer were performed at normal operating speed. To place the system in full speed operation the following procedure was used.

a) All data switches on the computer's control panel were placed in the up position.

b) The HI, LG, DEP, and EXAM toggle switches were checked to see that they had returned to their normal up position.

c) The HOLD control was toggled up.

d) The metallic STEP switch would remain down. The yellow STEP switch would be pushed down, because full speed operation was desired.

e) While holding the RESET switch up, the HOLD switch was toggled down. The RESET switch would then be released.

At the completion of the above procedure, the computer would be operating at 2 megahertz (MHz).

**Memory Limitations**

For this simulation, an Intel B1702A memory chip was employed.
According to Intel literature (34), this memory chip can be accessed at a maximum rate of 650 nsec. That means that the computer would have to be slowed down to accommodate this. On the contrary, the computer was tested at 2 MHz because the faster memory will be incorporated at a future date. The system worked remarkably well, and only on rare occasions did it bomb out and need to be reset. This could be attributed to the use of the slower memory. However, as long as the controller was not being used in actual fluoroscopic situations, full speed operation with this memory chip was feasible. Testing was in no way hampered by the memory.

**Modeling of the Interrupt Signals**

For this simulation, an interrupt signal had to be generated to simulate the video synchronization unit's interrupts. A square wave signal generator was used to input a 60 Hz input to a monostable multivibrator. Figure 43 shows the circuit used to simulate the 10-20 usec interrupting pulse.

For these tests, it was not necessary to input two different interrupt signals. The priority circuit was evaluated in Test 4 of single step testing. For that reason, both interrupt signals were generated by the one monostable multivibrator.

**Tests of Output**

The tests described below help demonstrate that the computer was operating in a correct fashion. They show that the computer responds
FIG. 43

GENERATION OF INTERRUPT SIGNALS

1. R and C are selected to achieve the appropriate output pulse.
to the interrupting frequency of 60 Hz. All of the control panel settings were used to generate and test the control outputs at this operating speed.

TEST 5  GO INSTRUCTION

To achieve updated information, the GO switch or the foot switch had to be depressed by the radiologist. As a test, a Hewlett Packard 5233L electronic counter was connected to the various computer generated outputs to determine if the controller was functioning correctly.

The specific test situation was set up as follows. The control panel settings were adjusted so that the UPDATE RATE was 30 frames/second, and the MODE of operation was 3-D. The PULSE WIDTH adjustment was set at the maximum of 6.0 msec. Table 3 shows the results.

The results show that the operation of the computer was correct. They went further to show that the fluoroscopic information was updated only if the GO instruction was specifically given by the radiologist.

TEST 6  MODE SELECTION

Selection of the MODE determines whether the fluoroscope presents three-dimensional or two-dimensional information. This particular software system pulses both x-ray sources in three-dimensional analysis but only the left x-ray source in two-dimensional analysis. By monitoring the output pulses, correct operation could be determined.
Table 3. Output from GO Switch Tests

<table>
<thead>
<tr>
<th>Output Analyzed</th>
<th>Counting Rate (pulses/second)</th>
<th>Counting Rate (pulses/second)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GO Switches Not Depressed</td>
<td>GO Switches Are Depressed</td>
</tr>
<tr>
<td>LXO</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>LXOFF</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>RXO</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>RXOFF</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>LTG</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>RTG</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>
For testing, the UPDATE RATE remained at 30 frames/second and the PULSE WIDTH continued to be 6.0 ms. The GO pushbutton was depressed at all times during the testing procedure. Table 4 illustrates the data attained as the MODE was varied from the 3-D to the 2-D positions.

The results showed that the left x-ray source was pulsed at 30 frames/second irrespective of the MODE selection. On the other hand, the right x-ray source was pulsed only when three-dimensional information was required. This data shows that the controlling system was fulfilling all operational requirements for MODE selection.

**TEST 7 UPDATE RATE**

The selection of the update rate is used to reduce radiation exposure. The radiologist has the ability to designate the number of times that the fluoroscopic information is being updated each second. To test the ability for the computer to regulate the update rate, analysis of the computer-generated output was performed.

The following experimental conditions were set up to test UPDATE RATE selection. PULSE WIDTH remained at its maximum setting of 6.0 msec; 3-D MODE of operation was selected. All measurements were taken with the GO switch depressed. Again, the electronic counter was employed to measure the frequency of the output signals. Table 5 contains the data taken as the UPDATE RATE was varied.

The LXO output pulse turned the left x-ray source on. The frequency at which this pulse was generated duplicated the rate at which the fluoroscopic information was generated. The test data
Table 4. Outputs with Varied MODE SELECTION

<table>
<thead>
<tr>
<th>Outputs Analyzed</th>
<th>Counting Rate (pulses/sec) 2-D Mode</th>
<th>Counting Rate (pulses/sec) 3-D Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>LXXO</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>LXXOFF</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>RXO</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>RXOFF</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>LTG</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>RTG</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>
Table 5. Computer Output for Varied Update Rates

<table>
<thead>
<tr>
<th>Update Rate Position (frames/second)</th>
<th>Counting Rate of LXO Output (pulses/10 seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>manual</td>
<td>updated once each time the switch was depressed</td>
</tr>
<tr>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>1.0</td>
<td>10</td>
</tr>
<tr>
<td>2.0</td>
<td>20</td>
</tr>
<tr>
<td>5.0</td>
<td>50</td>
</tr>
<tr>
<td>15.0</td>
<td>150</td>
</tr>
<tr>
<td>30.0</td>
<td>300</td>
</tr>
</tbody>
</table>
showed that the fluoroscopic information was updated according to the selection of the update rate by the radiologist.

TEST 8 PULSE WIDTH

Pulse Width

This test was developed to determine if the pulse width selected on the control panel generated the appropriate delay between when the x-ray source was turned on and when the x-ray source was turned off. This information was available by measuring the time delay between the LXC and the LXOFF control pulses.

An external circuit was developed to facilitate the measurement of the time delay by a Tektronix, Incorporated Type 545B oscilloscope. Figure 44 illustrates the setup that was employed. Test conditions were set up such that the update rate was 30 frames/second and the mode was three-dimensional. The GO switch was depressed at all times during the measurements. Table 6 shows the data obtained from the oscilloscope as the PULSE WIDTH was varied.

The output demonstrated that the pulse width of the controlling system was equal to that value selected on the control panel.
FIG. 44 TEST SETUP TO DETERMINE PULSE WIDTH
Table 6. Duration of X-Ray Pulse Width

<table>
<thead>
<tr>
<th>Pulse Width Selection (msec)</th>
<th>Pulse Width as Measured by the Oscilloscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>5.2 cm (20 μsec/cm) = 0.1 msec</td>
</tr>
<tr>
<td>0.5</td>
<td>5.0 cm (0.1 msec/cm) = 0.5 msec</td>
</tr>
<tr>
<td>1.0</td>
<td>5.0 cm (0.2 msec/cm) = 1.0 msec</td>
</tr>
<tr>
<td>1.5</td>
<td>7.4 cm (0.2 msec/cm) = 1.5 msec</td>
</tr>
<tr>
<td>2.0</td>
<td>9.9 cm (0.2 msec/cm) = 2.0 msec</td>
</tr>
<tr>
<td>4.0</td>
<td>7.9 cm (0.5 msec/cm) = 4.0 msec</td>
</tr>
<tr>
<td>6.0</td>
<td>6.0 cm (1.0 msec/cm) = 6.0 msec</td>
</tr>
</tbody>
</table>
V. CONCLUSIONS AND RECOMMENDATIONS

A microcomputer system has been presented to control a three-dimensional fluoroscope that will be built by Dr. Dale B. Rivers at the Virginia Polytechnic Institute and State University. For this reason, the actual manipulation of fluoroscopic equipment has not been tested. Substantial time has been spent analyzing the problem of three-dimensional fluoroscopy so that the development of this system would be a meaningful endeavor. This computer system has certainly demonstrated that it can offer the type of control necessary to manipulate extensive fluoroscopic systems.

This fluoroscopic control system can offer the radiologist versatility that no other system provides. The ability to select update rate lends itself to a large array of clinical procedures otherwise not considered under fluoroscopic analysis. For instance, the fluoroscope could make a single instantaneous image and hold it for analysis. At the other extreme, the same fluoroscopic apparatus could be used for real-time kinematical analysis. The computer controller makes this possible. A second feature, that lends versatility, is the selection of three-dimensional or two-dimensional analysis. The controller has the ability to manipulate the three-dimensional fluoroscopic apparatus in either of the operational modes.

This endeavor shows tremendous potential to reduce the excessive radiation exposure acquired during some clinical procedures. The combination of update rate and pulse width control facilitates dose
reduction. Pulsing the fluoroscope only when absolutely required can save radiation exposure. This application of the computer not only applies to three-dimensional analysis but to conventional two-dimensional analysis. Reduction is afforded because the system leaves the selection of update rate and pulse width to the professional discretion of the radiologist. The author is not aware of any other system that provides this option in fluoroscopic analysis.

To reemphasize, the application of this computer lies entirely on the selection of the appropriate fluoroscopic components. In fact, more time was spent selecting fluoroscopic equipment than was spent developing the computer controlling system. Initial constraints on the stereofluoroscope were set forth by Dr. Rivers (35-37) and those operational parameters were centered around the implementation of Perry's visualization system. Dr. Rivers realized that in a real-time fluoroscopic system the video constraints imposed the limiting conditions. From there, state-of-the-art technology was evaluated and selected to:

1) establish the fact that the stereofluoroscope could work;

2) design the computer controlling mechanism.

The author has described in great detail the selection of specific fluoroscopic and video components in Appendix C.

So many new technologies have been utilized in this development that the threat of double exposure to achieve stereoscopic information
deserves reevaluation. Exposure to radiation is always a main concern no matter what form of analysis radiological methods undertake. For reasons developed in Appendix C, the camera has the ability to utilize all radiographic information and relay it to the observer. Full evaluation of dose reduction must be determined to assess the transfer of radiation energy to visual fluoroscopic information.

Another aspect of dose reduction that requires investigation is the relationship between update rate and image quality. To convey this point, assume that a single fluoroscopic image is constantly being replayed. The noise, that is inherent to that static view, can be assessed by the viewer. If, on the other hand, a series of images are presented, the image quality of these instantaneous images may not be as important. The amperage of the x-ray tube may require that it be adjusted according to update rate to supply an acceptable image quality. Appendix B spends some time incorporating this question in such a manner that the computer may be implemented to solve the problem.

In summation, it is accurate to say that true stereoscopic information is available to radiologists by manipulating present two-dimensional, non-real-time radiographic apparatus. Only a few facilities throughout the world have access to stereo-cinefluoroscopic systems. Technology pertaining to stereoscopic visualization and video storage have advanced to the point that application of these developments can provide a working real-time stereofluoroscope with maximum consideration for radiation exposure levels. The control
mechanism designed here not only allows stereofluoroscopic analysis but deserves to have direct application made to conventional two-dimensional analyses for the purpose of dose minimization.
REFERENCES


APPENDIX A
SOFTWARE SYSTEM

The following computer program is the MAC80 cross-assembler's output. MAC80 was used to develop the software system for the microcomputer. Pages 116 through 132 represents the program that was used to test the control system. Pages 134 through 136 represent an optional software system that can be used to produce two pulses of x-rays during two-dimensional operation of the fluoroscope.

The MAC80 output consists of five basic types of information. As an example, below is a line of the MAC80 generated output.

```
0000   C37801    START:   JMP SETUP   ; INITIA ...
    A   B   C   D   E
```

Field A contains the hexadecimal memory address. The first two digits represent the HI memory address, and the second two digits represent the LO memory address. Field B contains up to three hexadecimal machine codes that begin at the memory address shown in Field A. The machine codes are assigned by the MAC80 assembler according to the mnemonic instructions given in fields C and D. Field C is the label field and field D is the mnemonic operational code. Field E is the comment field and serves no purpose as far as the MAC80 cross-assembler is concerned. For more specific information about MAC80, refer to ref. 33.

Below is the list of variables, followed by the computer printout.
$^{@SC}$ is the output port that signals the interfacing to latch the storage tube control byte.

$^{3SCL}$ is the memory location at HI 04H and LO C3H that contains the variable used to determine which storage tube has the stored fluoroscopic image.

$^{Al-A7}$ are all memory locations that are used in branch operations of the REDO section of the UPDAT subroutine.

$^{ACCUM}$ is the memory location at HI 04H and LO C4H. It is the first of eight memory locations that store the register variables used in interrupt servicing.

$^{CL}$ represents the output port used to nullify the GO instruction of the radiologist.

$^{CMODE}$ is a memory location that is jumped to if three-dimensional analysis is required. It is a portion of the first field write interrupt servicing subroutine. It initiates output of the appropriate interrupt instruction to allow three-dimensional analysis during the second field.

$^{CO}$ is a variable stored in the E register when interrupt servicing is performed. If equal to zero the REDO portion of the UPDAT subroutine must be performed.

$^{CONT2}$ represents the memory location HI 00H and LO 20H where the second field's write interrupt servicing subroutine begins. This is used during 2-D analysis.

$^{CONT3}$ represents the memory location HI 00H and LO 28H where the second field's write interrupt servicing subroutine begins.
This is used during 3-D analysis.

CONTR represents the memory location HI 00H and LO 10H where the second field's read interrupt servicing subroutine begins.

COUNT is a variable stored in register D when interrupt servicing is being performed. COUNT stores the number of times that the stored fluoroscopic image has been redisplayed.

CR is a memory location used in a branch operation.

DUMB is a memory location at HI 04H and LO 11H. It is incremented in the pulse width timing loop to use up a certain amount of time.

HERE is a memory location that is specified for a branch operation.

INGO represents an input device select pulse that signals the interfacing when the computer is ready to input the GO instruction.

ISTAT represents an output device select pulse that signals the interfacing when the interrupting restart code is to be output.

LOOP is a memory location of a branch operation.

LTG is a output port that is used to signal the left goggle's PLZT crystal.

LXO is the output port that signals the left x-ray source when it is to be turned on.

LXOFF is the output port that signals the left x-ray source when it is to be turned off.

MAIN is a memory location in a branch operation.
MODEP is the input device select pulse that signals the interfacing when the MODE variable is to be input to the computer.

NOR2 is the memory location for a branch operation.

NOW2 is the memory location for a branch operation.

PROCE begins a portion of the UPDAT subroutine that is processed if the go instructions is given by the radiologist.

R is a subroutine within the UPDAT subroutine that is called if the storage tubes are to be placed in the read mode. This means that the fluoroscopic information is to be replayed.

RAT represents an input device select pulse that is used to signal the interfacing that the update rate variable is to be input to the computer.

RATEL represents the memory location HI 04H and LO C2H. It stores the update binary counter limit that is assigned during the REDO portion of the UPDAT subroutine.

RCONT is a memory location that specifies a branch operation's destination. It is within the first field read interrupt service subroutine.

READ is the location HI 00H and LO 08H where the first field read interrupt service subroutine begins.

REDO is a portion of the UPDAT subroutine that assigns the binary counter limit to the input update rate variable. The binary counter limit designates the number of times that a fluoroscopic image is to be replayed before being updated.
RF1 is an output device select pulse port that signals external
circuitry to allow the first field vertical retrace signal
to interrupt the computer.

RF2 is an output device select pulse port that signals external
circuitry to allow the second field vertical retrace signal
to interrupt the computer.

RTG represents an output device select pulse that signals the
right goggle's PLZT crystal.

RXO represents an output device select pulse that signals the
right x-ray source when it is to be turned on.

RXOFF represents an output device select pulse that signals the
right x-ray source when it is to be turned off.

SAME is the beginning location of a portion of the UPDAT sub-
routine. It is performed if the update rate has not been
changed by the radiologist. If the update rate has been
changed, computer operation is not transferred to this
location.

SCR1 is a variable that is output to place the storage tubes
in the read mode of operation. The first storage tube
contains the recorded fluoroscopic information.

SCR2 is a variable that is output to place the storage tubes in
the read mode of operation. The second storage tube
contains the recorded fluoroscopic information.

SCWI is a storage tube control word. It places the storage tubes in
the write mode of operation. The first storage tube will record
the fluoroscopic information.

SCW2 is a storage tube control word. It places the storage tubes in the write mode of operation. The second storage tube will record the fluoroscopic information.

SETUP is a memory location of a branch operation. It is located within the START routine.

START is the memory location HI 00H and LO 00H. It is the first memory location of the procedure to initialize all variables and circuits.

STORE represents the memory location HI 04H and LO COH. This location contains the variable that is input to determine the x-ray pulse width.

TAB is the variable stored in the B register where interrupt servicing is taking place. It contains the update rate variable that is input to the computer.

Ti-T4 are memory locations used in branch operations during the x-ray pulse width timing loops.

UPDAT is the subroutine that is called during any second field interrupt servicing subroutine. This portion of the program determines whether the fluoroscopic image will be updated or replayed.

W is the subroutine contained within the UPDAT subroutine that generates the storage tube control word for recording operation.
W1 - W3 represents the memory locations designated for branch operations.

WIDTH represents the input device select pulse port used to signal the interfacing when the x-ray pulse width variable is to be input to the computer.

WR is a memory location identified for the purpose of a branch operation.

WRITE is memory location HI 00H and LO 18H. It is the initial location for the first field write interrupt service subroutine.

Z1 - Z2 are memory locations specified for branch operations within the x-ray pulse width timing loops.
;**********************************************************************
;************ COMMENTS ************
;***** REGISTER LOCATIONS FOR INTERRUPT SUBROUTINE
; REGISTER A WORKING REGISTER
; REGISTER B TAB
; REGISTER C NOT USED AT THIS TIME
; REGISTER D COUNT
; REGISTER E CO
; REGISTER PAIR H LOCATION M
;************ COMMENTS ************
;UPDATE RATES (FRAMES/SECOND)
;FOR 30 INPUT 00000000B
;FOR 15 INPUT 00000010B
;FOR 5  INPUT 00000110B
;FOR 2  INPUT 00001111B
;FOR 1  INPUT 00011110B
;FOR 0.5 INPUT 00111100B
;FOR 0.3 INPUT 0110100B
;MANUAL INPUT 1111111B
;FOR ALL OTHER INPUTS GO TO READ Routines
;***********************************************************************
;PULSE WIDTH
;INPUT NUMBER BETWEEN 00000000R & 11111111B
;***********************************************************************
;MODE INPUTS
;FOR 2-D INPUT 00000010B
;FOR 3-D INPUT 00000011B
;***********************************************************************
;GO INSTRUCTION INPUT
;TO UPDATE FLUOROSCOPY INFORMATION
;INPUT 00000000B
;***********************************************************************
**THIS REGION SPECIFIES SPECIFIC VARIABLES**

; JOC1 SCW1 EQU 1100001B ; WRITE S-C 1, ERASE S-C 2
; JOC2 SCW2 EQU 00011100B ; WRITE S-C 2, ERASE S-C 1
; JOC3 SCR1 EQU 1010001B ; READ S-C 1, ERASE S-C 2
; JOC4 SCR2 EQU 0001100B ; READ S-C 2, ERASE S-C 1

; OUTPUT DEVICE SELECT PULSES

; 0001 @SC EQU 1 ; PORT FOR CONTROL OF SCAN-CONVERTER
; 0002 LXO EQU 2 ; PORT FOR PULSING LT. X-RAY TUBE ON
; 0003 LXOFF EQU 3 ; PORT FOR PULSING LT. X-RAY TUBE OFF
; 0004 RXO EQU 4 ; PORT FOR PULSING RT. X-RAY PULSE ON
; 0005 RXOFF EQU 5 ; PORT FOR PULSING RT. X-RAY PULSE OFF
; 0006 LTG EQU 6 ; PORT FOR PULSING LT. GOGGLE ON
; 0007 RTG EQU 7 ; PORT FOR PULSING RT. GOGGLE ON
; 0008 RF1 EQU 8 ; PORT TO ALLOW FIRST FIELD RETRACE TO INTERRUPT
; 0009 RF2 EQU 9 ; PORT TO ALLOW SECOND FIELD RETRACE TO INTERRUPT
; 000A ISTAT EQU 10 ; PORT TO SET VECTORED INTERRUPT
; 000B CL EQU 11 ; PORT TO CLEAR OPERATORS GO INSTRUCTION

; INPUT DEVICE SELECT PULSES

; 0001 WIDTH EQU 1 ; PORT TO INPUT X-RAY PULSE WIDTH
; 0002 MODEP EQU 2 ; PORT TO INPUT MODE, 2-D OR 3-D
; 0003 RAT EQU 3 ; PORT TO INPUT UPDATE INFORMATION
; 0004 INGD EQU 4 ; PORT TO INPUT GO OR STOP INSTRUCTION

; MEMORY LOCATIONS

; 04C0 STORE EQU 4C04 ; LOCATION FOR PULSE WIDTH DATA
; 04C1 DUMB EQU 4C1H ; DUMMY VARIABLE TO WASTE TIME DURING TIMING LOOP
; 04C2 RATEL EQU 4C2H ; LOCATION TO STORE UPDATE COUNTER
; 04C3 @SCL EQU 4C3H ; LOCATION TO STORE WHICH S-C HAS THE STORED INFO.
; 04C4 ACCUM EQU 4C4H ; FIRST LOC. IN MEMORY TO STORE VARS. FOR INTERRUPT.
0000 ORG 00000
0000 C37801 START: JMP SETUP
0178 ORG 376
0178 D10000 SETUP: LXI B,0
0178 110000 LXI D,0
017E 21C404 LXI H,ACCUM
0181 70 MOV M,B
0182 23 INX H
0183 71 MOV M,C
0184 23 INX H
0185 72 MOV M,D
0186 23 INX H
0187 73 MOV M,E
0188 31BF04 LXI SP,4BFH
0188 3EA1 MVI A,SCR
018D D301 OUT ASC
018F 3ECF MVI A,317Q
0191 D30A OUT ISTAT
0193 D308 OUT RF1
0195 FB EI
0196 C39901 JMP MAIN
0199 00 MAIN: NOP
019A C39A01 LOOP: JMP LOOP

;*******************************
;**** RESTART ****
;INITIATE SETTING UP ALL COUNTERS AND RAM MEMORY*
;PACKED MAY 1977
;CLEAR REGISTER PAIR B
;CLEAR REGISTER PAIR D
;LOCATE STACK POINTER
;MAY WANT TO ERASE SCAN-CONVERTER IN TIMING LOOP*
;S-C STATUS
;SEND S-C STATUS TO S-C OUTPUT PORT
;SET FLIP-FLOP FOR 1ST FIELD RETRACE
;WAIT FOR INTERRUPT

;<<<<<<<<<<<<< OPTIONAL PROGRAM >>>>>>>>
;<<<<<<<<<<<<< OPTIONAL PROGRAM >>>>>>>>>>
;<<<<<<<<<<<<< OPTIONAL PROGRAM >>>>>>>>>>
ORG J0033JQ  ;****INTERRUPT****
D302 WRITE: OUT LX0  ;OUTPUT PORT FOR LEFT X-RAY SOURCE
C33200  JMP W1  ;
50  ORG  ; PACKED MAY 1977
D306 W1: OUT LTG  ;OUTPUT PORT FOR LT. GOGGLE
TIMING LOOP

F5  PUSH PSW
C5  PUSH B
D5  PUSH D
E5  PUSH H
DB01  IN WIDTH  ;INPUT PORT FOR X-RAY PULSE WIDTH
21C004  LXI H,STORE  ;
77  MOV M,A  ;SAVE THE TIMING VARIABLE FOR THE SECOND FIELD
77  MOV M,A
77  MOV M,A
77  MOV M,A
77  MOV M,A
77  MOV M,A
77  MOV M,A
30  INR A
3D  DCR A
CA5700  JZ Z1  ;JUMP IF ZERO
21C104 T2: LXI H,DUMB  ;
34  INR M
7F  MOV A,A
30  DCR A
CA5600  JZ T1  ;JUMP IF ZERO
<table>
<thead>
<tr>
<th>Address</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0053 C34A00</td>
<td>JMP T2</td>
</tr>
<tr>
<td>0056 34 T1:</td>
<td>INR M</td>
</tr>
<tr>
<td>0057 34 Z1:</td>
<td>INR M</td>
</tr>
<tr>
<td>0058 35</td>
<td>DCR M</td>
</tr>
<tr>
<td>0059 34</td>
<td>INR M</td>
</tr>
<tr>
<td>039A 35</td>
<td>DCR M</td>
</tr>
<tr>
<td>0358 D303</td>
<td>OUT LXOFF</td>
</tr>
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</table>

; OUTPUT PORT FOR TURNING OFF X-RAY PULSE

<table>
<thead>
<tr>
<th>Address</th>
<th>Contents</th>
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<tbody>
<tr>
<td>0050 DB02</td>
<td>IN MODEP</td>
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<tr>
<td>005F D603</td>
<td>SUI 3</td>
</tr>
<tr>
<td>0361 CA7000</td>
<td>JZ CMODE</td>
</tr>
<tr>
<td>0064 3EE7</td>
<td>MVI A,347Q</td>
</tr>
<tr>
<td>0066 D30A</td>
<td>OUT ISTAT</td>
</tr>
<tr>
<td>0068 D309</td>
<td>OUT RF2</td>
</tr>
<tr>
<td>006A E1</td>
<td>POP H</td>
</tr>
<tr>
<td>006B D1</td>
<td>POP D</td>
</tr>
<tr>
<td>006C C1</td>
<td>POP B</td>
</tr>
<tr>
<td>006D F1</td>
<td>POP PSW</td>
</tr>
<tr>
<td>006E F8</td>
<td>EI</td>
</tr>
<tr>
<td>006F C9</td>
<td>RET</td>
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</table>

; TIMING LOOP

<table>
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<tr>
<th>Address</th>
<th>Contents</th>
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<tr>
<td>0073 3EEF CMODE</td>
<td>MVI A,357Q</td>
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<tr>
<td>0072 D30A</td>
<td>OUT ISTAT</td>
</tr>
<tr>
<td>0074 D309</td>
<td>OUT RF2</td>
</tr>
<tr>
<td>0076 E1</td>
<td>POP H</td>
</tr>
<tr>
<td>0077 D1</td>
<td>POP D</td>
</tr>
<tr>
<td>0078 C1</td>
<td>POP B</td>
</tr>
<tr>
<td>0079 F1</td>
<td>POP PSW</td>
</tr>
<tr>
<td>007A F6</td>
<td>EI</td>
</tr>
<tr>
<td>007B C9</td>
<td>RET</td>
</tr>
</tbody>
</table>

; SET INTERRUPT STATUS

; ENABLE INTERRUPT

; *************************************************************************************************
0028 D304 CONT3: OUT RX0
002A C3A00J JMP W3
00A0 ORG 160
00A0 D307 W3: OUT RTG
00A2 7F MOVA,A
00A3 7F MOVA,A
00A4 F5 PUSH PSW
00A5 C5 PUSH B
00A6 D5 PUSH D
00A7 E5 PUSH H
00A8 21C004 LXI H,STORE
00AB 7E MOVA,M
00AC 7E MOVA,M
00AD 7E MOVA,M
00AE 7E MOVA,M
00AF 7E MOVA,M
00B0 7E MOVA,M
00B1 7E MOVA,M
00B2 7E MOVA,M

;***********************************************************************
;                   <<<<<<< SECOND FIELD WRITE >>>>>>       (3-D)       *
;***********************************************************************

;OUTPU PORT FOR RIGHT X-RAY SOURCE
;PACKED MAY 1977
;THIS REPLACES THE INPUT OF HLONG FOR TIMING LOOP
;TIMING LOOP
;THIS REPLACES THE INPUT OF HLONG FOR TIMING LOOP
;MOVE STORED VALUE FOR X-RAY PULSE TIMING LOOP
0083 3C      INR A      ;
0084 3D      DCR A      ;
0085 CAC500 JZ Z2      ;JUMP IF ZERO
0088 21C104 T4: LXI H,0UMB    ;
008B 34      INR M      ;
008C 7F      MOV A,A     ;
008D 3D      DCR A      ;
008E CAC400 JZ T3      ;JUMP IF ZERO
00C1 C3B800 JMP T4     ;
00C4 34      INR M      ;
00C5 34      INR M      ;
00C6 35      DCR M      ;
00C7 34      INR M      ;
00C8 35      DCR M      ;
00C9 0305 OUT RXOFF   ;OUTPUT TO TURN OFF RIGHT X-RAY PULSE
                       ;TIMING LOOP
                       ;SET COUNTERS
00CB 21C404 LXI H,ACCUM    ;
00CE 46      MOV B,M     ;
00CF 23      INX H      ;
00D0 4E      MOV C,M     ;
00D1 23      INX H      ;
00D2 56      MOV D,M     ;
00D3 23      INX H      ;
00D4 5E      MOV E,M     ;
ORG 000340Q

0020 C300J1 CONT2: JMP w2
0100 ORG 256
0100 D307 w2: OUT RTG
0102 F5 PUSH PSW
0103 C5 PUSH B
0104 D5 PUSH D
0105 E5 PUSH H
0106 21C404 LXI H,ACCUM
0109 46 MOV B,M
010A 23 INX H
010B 4E MOV C,M
010C 23 INX H
010D 56 MOV D,M
010E 23 INX H
010F 5E MOV E,M
<table>
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<tr>
<th>Address</th>
<th>Code</th>
<th>Instruction</th>
<th>Notes</th>
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<tbody>
<tr>
<td>0110</td>
<td>C00002</td>
<td>CALL UPDATE</td>
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</tr>
<tr>
<td>0113</td>
<td>D308</td>
<td>OUT RFI</td>
<td></td>
</tr>
<tr>
<td>0115</td>
<td>21C404</td>
<td>LXI H, Accum</td>
<td></td>
</tr>
<tr>
<td>0118</td>
<td>70</td>
<td>MOV M, B</td>
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</tr>
<tr>
<td>0119</td>
<td>23</td>
<td>INX H</td>
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<tr>
<td>011A</td>
<td>71</td>
<td>MOV M, C</td>
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<td>011B</td>
<td>23</td>
<td>INX H</td>
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<tr>
<td>011C</td>
<td>72</td>
<td>MOV M, D</td>
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<tr>
<td>011D</td>
<td>23</td>
<td>INX H</td>
<td></td>
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<tr>
<td>011E</td>
<td>73</td>
<td>MOV M, E</td>
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<tr>
<td>011F</td>
<td>E1</td>
<td>POP H</td>
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<tr>
<td>0120</td>
<td>D1</td>
<td>POP D</td>
<td></td>
</tr>
<tr>
<td>0121</td>
<td>C1</td>
<td>POP B</td>
<td></td>
</tr>
<tr>
<td>0122</td>
<td>F1</td>
<td>POP PSW</td>
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</tr>
<tr>
<td>0123</td>
<td>FB</td>
<td>EI</td>
<td></td>
</tr>
<tr>
<td>0124</td>
<td>C9</td>
<td>RET</td>
<td></td>
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;*******************************************************************************
0008 ORG 000010Q
0008 C33201 READ: JMP RCONT
0132 ORG 306
0132 D306 RCONT: OUT LTG
0134 F5 PUSH PSW
0135 3ED7 MVI A,327Q
0137 D30A OUT ISTAT
0139 D309 OUT RF2
013B F1 POP PSW
013C FB EI
013D C9 RET

;*********************************************************************
; ;<<<<<< FIRST FIELD READ >>>>
; ;********INTERUPT*****
; ;********INTERUPT*****
; ; PACKED MAY 1977
; ; OUTPUT PORT FOR THE LT. GOGGLE
; ; SET INTERRUPT STATUS
; ; SET FLIP-FLOP FOR SECOND RETRACE
; ;
ORG 000020Q
C34601 CONTR: JMP CR
ORG 326
D307 CR: OUT RTG
F5 PUSH PSW
C5 PUSH B
D5 PUSH C
E5 PUSH H
21C404 LXI H, ACCUM
46 MOV B,M
23 INX H
4E MOV C,M
23 INX H
56 MOV D,M
23 INX H
5E MOV E,M
0156 C00002 CALL UPDATE ;
0159 0308 OUT RF1 ;SET FLIP-FLOP FOR FIRST RETRACE *
015B 21C404 LXI H, ACCUM ;
015E 70 MOV M,B ; *
015F 23 INX H ; *
0160 71 MOV M,C ; *
0161 23 INX H ; *
0162 72 MOV M,D ; *
0163 23 INX H ; *
0164 73 MOV M,E ; *
0165 E1 POP H ; *
0166 D1 POP D ; *
0167 C1 POP B ; *
0168 F1 POP PSW ; *
0169 F8 EI ; *
016A C9 RET ; *

**********************************************************************************
ORG 512
0200 DB03 UPDATE: IN RAP
0202 88 CMP B
0203 CA1002 JZ SAME
0206 47 MOV B,A
0207 D308 OUT CL
0209 11000 J LXI B,0000H
020C CD9702 CALL R
020F C9 RET
0210 DB04 SAME: IN INGC
0212 D600 SUI O
0214 CA1002 JZ PROCE
0217 CD9702 CALL R
021A C9 RET
021B 78 PROCE: MOV A,E
021C D600 SUI O
021E CA3702 JZ REDO
0221 21C204 HERE: LXI H, RATEL
0224 7E MOV A,M
0225 BA CMP D
0226 CA31J2 JZ WR
0229 DA3102 JC WR
022C 14 INR D
022D CD9702 CALL R
0230 C9 RET
0231 1600 WR: MVI D,0000
0233 CD8202 CALL W
0236 C9 RET
;THIS PART OF THE PROGRAM
;DETERMINES THE NUMBER OF TIMES THAT
;THE IMAGE IS TO BE REPLAYED BEFORE UPDATING

<table>
<thead>
<tr>
<th>Address</th>
<th>Opcode</th>
<th>Instruction</th>
<th>Notes</th>
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<tr>
<td>0237</td>
<td>21C204</td>
<td>KEO: RX1 H, RATEL</td>
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<tr>
<td>023A</td>
<td>78</td>
<td>MOV A, B</td>
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<td>023B</td>
<td>FE80</td>
<td>CPI 80H</td>
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<td>023D</td>
<td>CA6602</td>
<td>JZ A1</td>
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<td>0240</td>
<td>FE40</td>
<td>CPI 40H</td>
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<td>0242</td>
<td>CA6002</td>
<td>JZ A2</td>
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<td>0245</td>
<td>FE20</td>
<td>CPI 20H</td>
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<td>0247</td>
<td>CA4002</td>
<td>JZ A3</td>
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<tr>
<td>024A</td>
<td>FE10</td>
<td>CPI 10H</td>
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<td>024C</td>
<td>CA0002</td>
<td>JZ A4</td>
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<td>024F</td>
<td>FE08</td>
<td>CPI 08H</td>
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<td>CA8002</td>
<td>JZ A5</td>
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<td>0254</td>
<td>FE04</td>
<td>CPI 04H</td>
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<td>0256</td>
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<td>0259</td>
<td>FE02</td>
<td>CPI 02H</td>
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<td>025B</td>
<td>CA9002</td>
<td>JZ A7</td>
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<td>025E</td>
<td>1E00</td>
<td>MVI E, 0</td>
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<tr>
<td>0260</td>
<td>D308</td>
<td>OUT CL</td>
<td>CLEAR IN FLIP-FLOP</td>
</tr>
<tr>
<td>0262</td>
<td>CD8202</td>
<td>CALL W</td>
<td></td>
</tr>
<tr>
<td>0265</td>
<td>C9</td>
<td>RET</td>
<td></td>
</tr>
</tbody>
</table>
0266 3600 A1: MVI M,00H ;
0268 1E01  MVI E,1 ;
026A C32102  JMP HERE ;
026D 3601 A2: MVI M,01H ;
026F 1E01  MVI E,1 ;
0271 C32102  JMP HERE ;
0274 3605 A3: MVI M,05H ;
0276 1E01  MVI E,1 ;
0278 C32102  JMP HERE ;
027B 360E A4: MVI M,0EH ;
027D 1E01  MVI E,1 ;
027F C32102  JMP HERE ;
0282 3610 A5: MVI M,10H ;
0284 1E01  MVI E,1 ;
0286 C32102  JMP HERE ;
0289 363B A6: MVI M,3BH ;
028B 1E01  MVI E,1 ;
028D C32102  JMP HERE ;
0290 3663 A7: MVI M,63H ;
0292 1E01  MVI E,1 ;
0294 C32102  JMP HERE ;

;Determine which S-C is to be used
;output status and interrupt status
Q297 21C304 R: LXI H, @SCL
Q29A 7E MOV A, @M
Q29B E601 ANI 00000018
Q29D C2A902 JNZ NQR2
Q2A0 3E1A MVI A, SCR1
Q2A2 D301 OUT @SC
Q2A4 3ECF MVI A, 317Q
Q2A6 D30A OUT ISTAT
Q2A8 C9 RET
Q2A9 3E1A NQR2: MVI A, SCR2
Q2AB D301 OUT @SC
Q2AD 3ECF MVI A, 317Q
Q2AF D30A OUT ISTAT
Q2B1 C9 RET

Q2B2 21C304 W: LXI H, @SCL
Q2B5 34 INR M
Q2B6 7E MOV A, @M
Q2B7 E601 ANI 00000018
Q2B9 C2C502 JNZ NOW2
Q2BC 3E1C MVI A, S&W2
Q2BE D301 OUT @SC
Q2C0 3EDF MVI A, 337Q
Q2C2 D30A OUT ISTAT
Q2C4 C9 RET
Q2C5 3EC1 NOW2: MVI A, S&W1
Q2C7 D301 OUT @SC
Q2C9 3EDF MVI A, 337Q
Q2CB D30A OUT ISTAT
Q2CD C9 RET

;READ STATUS
;

;WRITE STATUS
;

END

;******************************************************************************
The remaining pages of this appendix present an alternate software program for the second field's two-dimensional interrupt service subroutine. The program replaces the previous subroutine starting at memory location HI 00H and LO 20H. This will provide a pulse of x-ray radiation from the left x-ray source for a second time.

The following additional variables are introduced if this software is used to replace that portion of the preceeding program:

T5-T6, Z3 are memory locations that are used to specify branch operations within the x-ray pulse timing loop.
;***************************************************************
; ; <<<< SECOND FIELD WRITE >>>>> 2-0
; *
; *
; ***************************************************************

0020  ORG 000040Q

0020 D302 CONT2: OUT LX0
;OUTPUT PORT FOR LEFT X-RAY SOURCE

0022 C3AA01 JMP W2
; *

01AA ORG 426
;PACKED MAY 1977

01AA D307 W2: OUT RTG
;OUTPUT PORT FOR TURNING ON LEFT OCULUS

01AC 7F MOV A,A
;THIS REPLACES THE INPUT OF HLONG FOR TIMING LOOP

01AD 7F MOV A,A
;THIS REPLACES THE INPUT OF HLONG FOR TIMING LOOP

01AE F5 PUSH PSW
;TIMING LOOP

01AF C5 PUSH B
; *

01B0 D5 PUSH D
; *

01B1 E5 PUSH H
; *

01B2 21C304 LXI H,STORE
; *

01B4 7E MOV A,M
;MOVE STORED VALUE FOR X-RAY PULSE TIMING LOOP

01B5 7E MOV A,M
; *

01B6 7E MOV A,M
; *

01B7 7E MOV A,M
; *

01B8 7E MOV A,M
; *

01B9 7E MOV A,M
; *

01BA 7E MOV A,M
; *

01BB 7E MOV A,M
; *

01BC 7E MOV A,M
; **
018D 3C INR A ;
018E 3D DCR A ;
018F CACF01 JZ Z3 ;JUMP IF ZERO
0192 21C104 T6: LXI H,DUMB ;
0195 34 INR M ;
0196 7F MOV A,A ;
0197 3D DCR A ;
0198 CACE01 JZ T5 ;JUMP IF ZERO
019B C3C201 JMP T6 ;
019E 34 T5: INR M ;
019F 34 Z3: INR M ;
01A0 35 DCR M ;
01A1 34 INR M ;
01A2 35 DCR M ;
01A3 0303 OUT LXOFF ;OUTPUT TO TURN OFF RIGHT X-RAY PULSE
                     ;TIMING LOOP

**********
01D5 21C404 LXI H, ACCUM
01D8 46 MOV B, M
01D9 23 INX H
01DA 4E MOV C, M
01DB 23 INX H
01DC 56 MOV D, M
01DD 23 INX H
01DE 5E MOV E, M
01DF C00002 CALL UPDATE
01E2 0303 OUT RF1
01E4 21C404 LXI H, ACCUM
01E7 70 MOV M, B
01E8 23 INX H
01E9 71 MOV M, C
01EA 23 INX H
01EB 72 MOV M, D
01EC 23 INX H
01ED 73 MOV M, E
01EE E1 POP H
01EF D1 POP D
01F0 C1 POP B
01F1 F1 POP PSW
01F2 FB EI
01F3 C9 RET

;************************************************************************************
APPENDIX B
This appendix has been assembled to serve as an instruction manual for the stereofluoroscopic control system. The text is written so that it can be isolated from the thesis as an independent unit. For this reason, some of the figures within this section have been reproduced from the text of the thesis.

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Constructing the Control System

Controlling System Components

An essential part of operating this system is making sure that all control hardware is assembled and properly connected to the Micro Designer® microcomputer. This off-the-shelf computer is the basis of all control functions. At this time the hardware is designed to work as a plug-in unit to this system.

The following components are required to assemble the stereo-fluoroscopic control system.

1) One standard Micro Designer® computer and its supporting power supply.

2) Eight Random Access Memory (RAM) chips. These are preferably the Intel 2102 16-pin chips with an access time of 500 nanoseconds (nsec).

3) Three Erasable Programmable Memory (EPROM) chips; the ones used in this simulation are pre-programmed Intel B1702A 24-pin chips. They are marked according to their assigned Hi hexadecimal memory address. Refer to the System Modification section of this manual for questions pertaining to the selection of this chip.

* Micro Designer® is a registered trademark of E&L Instruments, Inc.
4) The interface board shown in Fig. B1.

5) The control panel shown in Fig. B2.

6) The footswitch shown in Fig. B3.

7) Four pieces of #24 or #26 wire to make jumper connections on the computer's MB-80/B memory board. They should be no longer than 1 in. in length.

**Inserting the Memory Chips**

The Micro Designer® comes with one MB-80/B memory board that holds all of the memory chips. Remove this panel from the dual-wide Digital Equipment Corporation (DEC) sockets so that the memory chips may be put in place. Insert the eight RAM chips into the eight 16-pin sockets on the left side of the memory board as shown in Fig. B4. Secondly, the EPROM chips must be put in place. Figure B4 also shows the location of these 24-pin chips. It is imperative that each EPROM chip be placed in the location according to the HI hexa-decimal memory address that it indicated on the chip. Figure B4 shows the correct location of each EPROM chip.

When all of the memory chips are in place, it is necessary to make the appropriate jumper connections on the MB-80/B memory board. Figure B5 shows an enlarged view of this jumper region. In the lower left hand corner, three terminals marked X, Y, and Z can be located. A wire must connect the X and Y terminals. Immediately to the upper right of these three pins are five more solderless terminals. A wire must connect the E pin to the 0 pin. Above this, two rows of twenty
solderless terminals can be found. Two final wires must be used to make appropriate connections. One wire must jumper pin A to pin 1. A second must jumper pin D to pin 0.

The memory board at this point is complete and ready to be returned to the DEC socket of the computer.

**Inserting the Interface Circuit Board**

The interface board shown in Fig. B1 is inserted into any one of the empty DEC sockets of the Micro Designer®. If the board has been placed in its correct position the integrated circuit chips will face the front of the computer.

**Connection of the Control Panel to the Computer**

The control panel provides the input information to the computer through the interfacing board. All input connections are made by placing the appropriate wires that run from the control panel into their corresponding input sockets on the interfacing board. Twenty-four wires are bound within a single cable that runs from the control panel. Each wire is labeled. Each wire must be placed in the appropriate socket shown in Fig. B6. The wire labels match the socket labels for each connection identically.

The control panel also provides all power to the computer. Connect the AC power plug that runs to the computer power supply to the AC power receptor plug of the control panel. **Make sure that power is not applied to the control panel when this is being done.**
FIG. B6 INTERFACE BOARD SOCKETS
Connection of the Foot Switch

Three labeled wires run from the footswitch. Each must be placed in its appropriate sockets on the interfacing board. The wire labels match identically with the appropriate labels of the sockets, as shown in Fig. B6.

Connection of Computer Output

Figure B6 shows the locations of the output sockets that provide output control signals to the fluoroscopic and video equipment. Below are the output signal labels.

- **LXO**: This output signal turns the left x-ray source on.
- **LXOFF**: This output signal turns the left x-ray source off.
- **RXO**: This output signal turns the right x-ray source on.
- **RXOFF**: This output signal turns the right x-ray source off.
- **LTG**: The left goggle is synchronized with the first field of video information by a signal from this socket.
- **RTG**: The right goggle is synchronized with the second field of video information by a signal from this socket.

Storage Tube Output

Eight bits of information (A0-A7) controls the storage tube operation and the video switching circuitry.

*The signals are TTL compatible, 500 ns, negative-going pulses.*
Operating the Computer Controller

Having made all of the hardware connections described above, the controller is ready to begin operation. The next requirement is supplying power to the system. Before plugging in the controller power cord, check to see that the ON-OFF POWER switch is in the OFF position. If this switch is off, the power cord that runs to the control panel can be plugged in.

From this point on, all control operations can be directed by manipulating the control panel only. When ready to begin the fluoroscopic control system, turn the POWER switch on. TURN THE POWER SWITCH OFF IF ANYTHING APPEARS TO BE UNUSUAL. The computer is immediately performing whatever operations are required to make the fluoroscope work. All fluoroscopic function is controlled by the information that is input to the control panel by the radiologist. Below is a brief description of each control that the radiologist has access to.

POWER Switch . . .

The POWER switch controls all power that goes to the computer and interfacing circuits. If there is any doubt about the computer's operation, TURN THE POWER SWITCH OFF.

MODE Toggle Switch . . .

This switch is positioned according to the manner in which the fluoroscopic information is to be presented. The radiologist has the ability to select two-dimensional or three-dimensional
information by selecting the appropriate toggle switch position.

PULSE WIDTH...

The radiologist selects the x-ray pulse width duration by positioning the rotary switch to the appropriate setting.

UPDATE RATE...

The radiologist also has control over the rate at which the fluoroscopic information is rejuvenated. When the MANUAL setting is selected, the GO pushbutton must be depressed for each frame of updated information.

GO switch...

Pressing this switch signals the computer to update the fluoroscopic information according to the rate selected by the radiologist. If the GO switch is released, all updating stops.

RADIATION LIGHT...

The light mounted on the control panel signals the radiologist when the x-ray sources are pulsed on. This is simply a safety precaution to alert the radiologist when x-rays are being produced.

Trouble Shooting

If there are any problems with the operation of the controlling system, the steps outlined below should be performed. They should
be performed in the order listed.

1) Momentarily turn the POWER switch off to clear the computer and start the control procedure again. If normal operation does not begin, proceed to the next step.

2) Check all of the control system hardware to see that it is properly connected. Follow the setup procedures outlined earlier in this manual.

3) If the computer is still not operating, check the integrated circuit chips on the interfacing board. To pull chips from the sockets use only a small screwdriver with a blade of about 1/4 in. wide. The chips can easily be pried from the sockets with the use of the screwdriver. This will prevent the chips and the wire-wrapping from being destroyed. Figure B1 shows the interfacing circuit board, and lists the exact chip numbers to be used when replacement is necessary.

4) If the control system does not work at this point the text of the thesis should be consulted. From this point on, changes require modification in the hardware or software. The computer has been extensively tested to eliminate the system's design problems. Modifications should not be made unless the system is completely understood.
System Modifications

Changing the Memory

The memory employed in this simulation is not fast enough to assure fail-safe operation of the controller. FOR THAT REASON, THE EXISTING MEMORY SHOULD NOT BE INCORPORATED IN ACTUAL FLUOROSCOPIC SITUATIONS. The program should be loaded into a faster memory chip that has an access time of 500 nsec or less. The Intel 8708 may prove beneficial. Incorporating this chip would require that a second memory board be purchased and that the software be transferred from the Intel 1702A to the Intel 8708.

Adding an Optional Program

An optional program can be adapted into this system readily. Figure B7 shows a portion of the present software system. The jump instruction (LOOP: JUMP LOOP) at memory location H1 01H and L0 9AH can be replaced to convert computer operation to the optional program. Addition of an optional program will not cause any alterations in the control of the fluoroscopic apparatus as long as some general constraints are observed. The constraints are outlined below.

1) The program may not use interrupt servicing. All interrupt servicing is set aside for fluoroscopic control.

2) The first 2K of memory should not be used. This is reserved for fluoroscopic control. Memory address H1 00H L0 00H through H1 02H L0 FFH is non-volatile
0000  ORG 000000Q
0030  C37801 START: JMP SETUP
0178  ORG 376
0178  010000 SETUP: LXI B,O
0178  110000 LXI D,O
017E  21C404 LXI H,ACCUM
0181  70 MOV M,B
0182  23 INX H
0183  71 MOV M,C
0184  23 INX H
0185  72 MOV M,D
0186  23 INX H
0187  73 MOV M,E
0188  31BF04 LXI SP,4BFH
018B  3EA1 MVI A,SCR1
0190  0301 OUT 3SC
0194  3ECF MVI A,317Q
0198  030A OUT ISTAT
019C  0308 OUT RFI
019F  F8 EI
0196  C39001 JMP MAIN
0199  00 MAIN: NOP
019A  C39A01 LOOP: JMP LOOP

**********************************************************************
****** RESTART ******
****** INITIATE SETTING UP ALL COUNTERS AND RAM MEMORY **************
****** PACKED MAY 1977 ********
****** CLEAR REGISTER PAIR B ********
****** CLEAR REGISTER PAIR D ********
****** LOCATE STACK POINTER ********
****** MAY WANT TO ERASE SCAN-CONVERTER IN TIMING LOOP ********
****** S-C STATUS ********
****** SEND S-C STATUS TO S-C OUTPUT PORT ********
****** SET FLIP-FLOP FOR 1ST FIELD RETRACE ********
****** WAIT FOR INTERRUPT ********

**********************************************************************

Fig. 87 MAC80 Program
memory used to store the control software. Memory address
HI 04H LO 00H through HI 04H LO FFH is random access memory
used for the stack and miscellaneous variables.

3) The stack may be used provided that no more than about
100 memory locations are used at any one time.

4) All registers may be used. The fluoroscopic control system
automatically protects register values and prevents their
destruction.

5) If input or output operations are to be used, it is important
to remember that some of the ports are currently being
employed for fluoroscopic control. Do not use input ports
1-4. Do not use output ports 1-11.

A Specific Optional Program

As mentioned in Chapter 5, it may be advantageous to use an
optional program to control the fluoroscopic image quality. Image
quality is a function of many things. Basically it is related to
the x-ray tube voltage and current, and the time that the tube is
turned on. Another factor that may be involved with image quality
is the update rate. As far as the radiologist is concerned, a
high quality image may not have to be generated if a fast update
rate is selected. On the other hand, if a single image is to be
analyzed, the image quality may have to be noticeably better. The
exact relation that is involved with this phenomenon is not determined
at this point. Some work may be required in this area to facilitate
efficient operation of this fluoroscopic controller.
SPECIFICS PERTAINING TO THE STEREOFLUOROSCOPIC EQUIPMENT

State-of-the-art technology is being implemented in this stereofluoroscopic system. The critical timing constraints imposed by the stereoscopic visualization system has required implementation of technology that has come into existence only in the last several years. The problem that arose was concerned with presenting a new fluoroscopic picture each 1/60 of a second.

Neither the image intensifier nor the grid-pulsed x-ray tubes impose any problem. Their response is very quick. Similarly, the decay times associated with these components are in the nanosecond range. These components pose no problem in presenting a new fluoroscopic image each 1/60 of a second. Problems arise when the discriminate images have to be recorded by a video camera. The first fluoroscopic image must be translated into the first field video signal and the second discriminate image must be translated into the second field video image.

One method of satisfying this requirement is to use two plumicon cameras. A mirror could be used to direct the image intensifier's light image output to one of the cameras each 1/60 of a second. This would only require that the mirrors be synchronized with the x-ray sources. Electronic circuitry could direct the first field of video information from the first camera and the second field of video information from the second camera to the video monitor and the storage tubes. Although this method would provide two discriminate
views to be displayed, this method also proves unsatisfactory as far as dose exposure is concerned. This is because half of the generated information is thrown away to create the stereo image. Two complete images are built up on the storage targets of the cameras. Only one field of information is used from each of the cameras. That means that only half of the information obtained when radiation is exposed to the patient is used.

An alternative is to use one camera to record both discriminate images. Because the discriminate images must be presented at a rate of 60 Hz, a conventional television camera will not work. When the camera target is pulsed with one light image it takes at least one complete frame scan to clear the target area so that the next light image may be recorded by the target area. This allows the maximum update rate of 30 frames per second. Radio Corporation of America, General Electric, and Fairchild Semiconductor are three organizations that have recently developed a television camera that will allow a complete image to be recorded each 1/60 of a second.

This new television camera is a solid state device that allows a completely new field of information to be recorded each 1/60 of a second. Because the light integrating areas of the target surface are solid state cells, they can build up a charge almost instantaneously. For that reason, only one field of information needs to be recorded by the storage target at any one time. The electron beam scans the entire charged surface once each field scan. At the end of the scan the whole surface is discharged and ready to receive new information.
During the vertical retrace time, the light image is exposed to the target, a charged pattern is formed upon the solid state areas, and the next field of information is ready to be translated into an analog output signal. Another attribute to this device is its ability to detect very low level light images. This technology will prove to be very beneficial in stereofluoroscopic applications.

Of the three companies that manufacture a solid state camera, Radio Corporation of America (RCA) provides the system that best suits the stereofluoroscope requirements. The resolution, gray scale, and sensitivity is within the limits imposed by this fluoroscopic application. This particular tube and camera sells for about 3,000 dollars.

The solid state camera is the electronic device that is required to provide the stereoscopic video signal. This camera technology may also show that it is possible to provide stereoscopic visualization of the fluoroscopic examination without radiation exposures above those acquired in conventional two-dimensional analysis. All of the image intensifier's light image is used to charge the surface of the camera target. Likewise, all of the charged surface is used to generate the analog signal. Theoretically, it would seem possible that this camera could allow stereoscopic analysis without a loss of any of the information obtained through radiation exposure.
VITA

The author was born in Grand Island, Nebraska on February 26, 1954. He has had the opportunity to reside in Denver, Colorado; Billings, Montana; McLean, Virginia, and Blacksburg, Virginia.

John entered Virginia Polytechnic Institute and State University in September of 1972. In June of 1976 he received a Bachelor of Science in Mechanical Engineering with an option in Biomedical Engineering. Immediately after completing that degree, he continued his education at Virginia Polytechnic Institute and State University towards a Master of Science in Mechanical Engineering. He is currently employed as an engineer for Corning Glass Works, at Corning, New York.

John Wesley Ellis
MICROCOMPUTER CONTROL OF A
THREE-DIMENSIONAL FLUOROSCOPE

by

John Wesley Ellis

(ABSTRACT)

A microcomputer controller has been developed to operate a stereofluoroscopic system that is to be built at Virginia Polytechnic Institute and State University. The purpose of the controller is to provide the radiologist with the maximum amount of fluoroscopic information with the minimum amount of radiation exposure.

The enhancement of the fluoroscopic information has been brought about through the implementation of real-time stereoscopic visualization. Stereoscopic visualization has been achieved by using PLZT crystal technology. The computer will control two grid-pulsed x-ray sources, an image intensifier, a solid-state video camera, a video monitor and the PLZT goggles to provide a stereoscopic image.

Dose reduction should be obtained through the use of the computer as the controlling mechanism. Two storage tubes will be synchronized with the fluoroscopic apparatus to allow repeated replay of an instantaneous fluoroscopic image. A wide range of update rates can be selected by the radiologist to yield maximum
radiation exposure savings. This stereofluoroscope is expected to provide real-time analysis with radiation exposures less than or equal to those achieved in conventional two-dimensional fluoroscopic analyses.