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ABSTRACT

The total system capability, including all the special purpose and general purpose hardware comprising the Airborne Electro-Optical Sensor Simulation (AEOSS) System, is described. The functional relationship between hardware portions is described together with interface to the software portion of the computer image generation. Supporting rationale for selection and arrangement of hardware is also provided, together with a description of the data base region. (Author/CMV)

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AIRBORNE ELECTRO-OPTICAL SENSOR SIMULATION SYSTEM

By

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The effort as documented in this report describes the total system capability. This includes a description of all the special purpose and general purpose hardware comprising the Airborne Electro-Optical Sensor Simulation (AEOSS) System. The functional relationship between hardware portions is described together with interface to the software portion of the computer image generation. Supporting rationale for selection and arrangement of hardware is also provided together with a description of the data base region.

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SUMMARY

PROBLEM: The development of concepts and algorithms for simulating for training, the performance characteristics of both Thermal Imagery Systems (TIS) and Low Light Level Television Systems (LLLTV) is critical to current and future simulator acquisition programs. The development of this technology will rely on Computer Image Generation (CIG) with emphasis upon data base characteristics and algorithms incorporated as part of system processing. The development and validation of this technology must be accomplished under static as well as dynamic conditions typical of that imposed upon a real-time full mission weapon system simulator.

APPROACH: The approach employed by AFHRL consisted of the development of a system with an optimum combination of flexibility with rapidity of simulation update to permit a wide variety of techniques to be investigated under both static and dynamic conditions. The system was designed to permit control over key simulation parameters and enable flexibility with respect to both data base and algorithm development. The capability of the AFHRL Simulation and Training Advanced Research System (STARS) was incorporated to the maximum extent and was further augmented through the use of Digital Equipment Corporation (DEC) minicomputers together with special purpose hardware to provide the speed with minimal compromise of flexibility. The special purpose hardware performed otherwise time-consuming functions of edge smoothing, transfer function generation and sensor noise. However, the hardware was designed to permit control over degree of smoothing, type of transfer function, and percent noise through software. A core memory was provided with sufficient size to hold a full frame of video information. An Ampex video disk and tape unit were provided so that individual frames could be accumulated on the disk and transferred to tape to permit dynamic sequences to be recorded for subsequent playback in real time. A data base was provided which included about 2500 square miles in the vicinity of Las Vegas. Both culture and terrain data as stored in Defense Mapping Agency (DMA) source data were included in the data base. In addition to this, ten special target areas, which included runway, power plant, and power lines were provided to supplement DMA source data.

RESULTS: The system was tested by generating both static and dynamic sequences over many portions of the data base. Dynamic sequences of three-minute duration were generated with no perceptible scene discontinuities during the transition from disk to tape. Update rates for individual frames covered from 10 to 30 seconds per frame, depending upon number of edges contained in the scene and degree of smoothing employed. Scenes were successfully generated employing many combinations of edge smoothing, transfer function and noise.

CONCLUSIONS: The system as developed under this effort has demonstrated usability as a research tool for conceptual and algorithm development applicable to TIS and

LLLTV simulation for training. The flexibility afforded through use of software emulation and variety of both terrain and culture which can be stored, processed and displayed should provide a very versatile and cost-effective tool for research purposes. It is anticipated that system capability will enable its use to support development activities in the area of texture synthesis for improving current technology as well as new concept developments employing non-linear techniques.

PREFACE

This effort was initiated by the Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio. The effort was conducted by the General Electric Company, Space Division, P. O. Box 2500, Daytona Beach, Florida 32015. Mr. Don Hayworth was the principal investigator for General Electric Company. Mr. William L. Foley, of the Simulation Techniques Branch, Advanced Systems Division, was the contract monitor for the Air Force Human Resources Laboratory. The effort was started in June 1976 and completed in December 1977.

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1.0 INTRODUCTION

The development of airborne infrared and low light level television systems has progressed to the extent that these systems are currently in use in the B-52 weapon system. Furthermore, these sensor systems are likely to be used in future weapon systems.

There is at present no efficient and cost-effective capability for training crews who must understand and operate these sensor systems. Such training must be based upon a knowledge of the capability inherent in present technology for satisfying this requirement and any subsequent development which may be required.

As a result, the Air Force Human Resources Laboratory (AFHRL) conducted exploratory programs which gained insight into the performance characteristics of these sensor systems and established potential suitability of computer image generation technology for satisfying the performance criteria imposed upon the hardware simulation system. These programs included cultural features only and were limited to static situations from the standpoint of the simulation and the output scenarios. General Electric supported this exploratory effort under Contracts F33615-74-5161 and F33615-75-C-5243.

As a next step, AFHRL initiated an advanced development program to expand simulation capability to permit generation of a dynamic simulation. The goal was the development of a system in which simulated flight maneuvers could be conducted over a limited gaming area containing natural terrain and cultural features while recording the output scenarios during this simulation. Time between updates was to be minimized so that recordings could be made in nonreal time with playback in real time. In this manner data base information and algorithms could be evaluated under dynamic simulation conditions representative of real-time systems.

A study program was initiated to determine on a competitive basis the best design for a system consistent with cost, maintainability, flexibility, and feasibility. The study programs were to result in a complete definition of all general purpose and special purpose hardware required together with requirements for software programs to effect the simulation. The study was to definitize the hardware and associated interface required between hardware components and for integration into the existing AFHRL facilities.

The study program was completed and the General Electric Company was selected to perform the follow-on effort. This follow-on effort covers the fabrication and implementation of the system defined by General Electric under Contract F33615-75-C-5287. This previous work was also under the direction of Mr. William L. Foley of the Simulation Techniques Branch of the Air Force Human Resources Laboratory at Wright-Patterson Air Force Base.

The effort performed under Contract F33615-76-R-0059 and described in this report, encompassed the design, fabrication, and implementation of the sensor simulation system selected by AFHRL from the part one study phase. The system implementation included the installation, checkout, and integration of the General Electric designed system into the Simulation and Training Advance Research System (STARS) simulation facility at AFHRL.

The tasks performed included the purchase of general purpose computational and video recording equipment, fabrication of special purpose hardware, and the adaptation/development of software to provide the sensor simulation programs that are compatible with the hardware configuration. The total system is capable of operating in a dynamic mode, i.e., the time intervals between successive scenarios are sufficiently short so that playback of successively recorded scenes can be accomplished at real-time rates. The simulation includes a data base which permits simulated flight profiles in any desired direction over the gaming area. The total effort included data base preparation from Defense Mapping Agency (DMA) source data and a simulation program to extract data, establish priorities, perform data transformation, insert the effect of atmosphere, and transfer characteristics of sensor system and prepare video for recording and display. The equipment involved is interfaced so that data may be transferred between general purpose and special purpose hardware and video recording and display hardware. The total system is configured to enable maximal use of general purpose computational equipment consistent with system flexibility and rapid simulation update.

The basic approach used in this program was developed during the Airborne Electro-Optical Sensor Simulation (AEOSS) design definition phase (Contract F33615-75-C-5287) and documented in the final report for that program phase. While modifications to the initially defined approach were made, by incorporating optional capabilities to better meet overall program objectives, the basic approach is still directly patterned after the hardware organization employed by General Electric in the design of real-time Computer Image Generation (CIG) systems. This is an important feature of the system, in that it ensures that all algorithms and techniques employed can be implemented in practical real-time systems. This important feature was also retained in the earlier all software simulation model developed under Contract F33615-74-5161 by General Electric.

Thus, the primary thrust of this effort was to reduce the per scene processing time exhibited by the earlier all software model to the minimum level consistent with retaining the major flexibility characteristics of the software model. The method employed involved a threefold approach. Special hardware logic modules were designed to perform those computational functions that are most time-consuming on general purpose computers and where flexibility could be retained with a hardware implementation. The computational capacity of the STARS Sigma 5 was augmented by adding two PDP 11/45 computers to the facility and allocating general purpose computational functions among the three machines. At the same time, many algorithms were modified and/or reprogrammed to achieve more efficient execution on the respective machines.

2.0 TECHNICAL DESCRIPTION

2.1 IMPLEMENTATION OVERVIEW

In addressing the implementation of this sensor simulation program, it is convenient to consider the program in two major parts. One part is the simulation model itself; i.e., the combination of hardware and software which, given any environment definition (data base) and assigned processing parameters, will produce a videotaped sequence validly simulating the desired sensor system display for the specified flight path, atmospheric and illumination effects, system parameters, etc. The second part of the total effort is the environment definition or data base provided with the system, including the development of the software for automatic transformation of DMA data to a terrain model suitable for processing by the sensor simulation system.

2.2 SENSOR SIMULATION DATA BASE

This simulation program included the development and delivery of a complete gaming area data base derived from Defense Mapping Agency Aerospace Center (DMAAC) source data and augmented with special targets of interest. In addition to the data base delivered with the system, special software data base transformation routines were developed for execution on the Sigma 5 computer. These routines accept DMAAC source data tapes and create additional data bases for the sensor simulation system.

2.2.1 DELIVERED DATA BASE—The gaming area selected for the initial data base is a one-degree latitude by one-degree longitude area which includes the city of Las Vegas, Nevada and the surrounding countryside primarily to the North, East, and West of Las Vegas.

The terrain model is a "real world" model consisting of continuously varying terrain over the entire gaming area. This terrain model was derived entirely from level 1 DMAAC digital source data for the area. In addition, all level 1 and level 2 DMAAC cultural (planimetric) features are included in the data base as defined in the digital source data.

Additional cultural features were added to the DMA source data to provide more detailed features for meeting research/evaluation objectives of the program. These features do not appear in the DMA source data, or do not appear with sufficient detail to permit level of detail and related model characteristics evaluations. Detailed features added include: (1) an airport complex; (2) an oil storage area; (3) a large factory complex; (4) a power plant; (5) a farming area; (6) a port city; and, (7) more detailed power poles, bridges, etc.

This data base is structured to allow for display of different levels of detail down to doors and windows for cultural objects. The data base can also be modified/updated under software control.

2.2.2 TRANSFORMATION SOFTWARE ROUTINES—General Electric also developed and delivered a data base transformation program that is capable of converting gridded source data as furnished by the DMAAC into a format suitable for processing by the sensor simulation equipment. This software program was implemented on the STARS Sigma 5 computer and can process any region of terrain within the continental U.S. of one-degree latitude by one-degree longitude in extent. This program accepts level 1 source data prepared by DMAAC on magnetic tape and creates a terrain model in accordance with operator specified accuracy criteria based upon the roughness of the terrain.

2.3 SENSOR SIMULATION SYSTEM

The AEOSS system as developed by the General Electric Company is depicted in Figure 1. All scene generation begins within the STARS Sigma 5 computer, passes to the two PDP 11/45 computers, then to the special purpose hardware modules. Once the special hardware processing is accomplished, a complete scene is loaded into the scene memory and then recorded on the video disk. When the video disk is fully loaded with 600 frames of video data, the video disk sequence is transferred to a video tape unit where longer sequences are assembled. Playback in real time from both the video disk and video tape is possible on a CRT which is also part of the AEOSS system. As each scene is generated, it is also displayed on the CRT to allow operator viewing of each frame as the sequence is prepared.

2.3.1 SENSOR SIMULATION SYSTEM EQUIPMENT—Equipment elements of this design configuration fall into three major categories; AFHRL STARS facility equipment, General Electric designed equipment and, vendor equipment purchased by General Electric and integrated into the system. Major equipment units are shown in Figure 2. The relation of this equipment to the STARS Sigma 5 is described in the following paragraphs.

2.3.1.1 STARS Sigma 5 Equipment—The Air Force Human Resources Laboratory STARS facility equipment available for this program consisted of a Xerox Data System Sigma 5 Central Processing Unit (CPU), core memory, and numerous peripherals controlled via a Multiplexing Input/Output Processor (MIOP). The CPU and MIOP each communicate with memory on a private bus connected to both memory banks through memory ports. The fastest port, usually referred to as Port C, on each bank is connected to the CPU. This port is preselected by a memory bank when no memory cycle is in progress, thus creating a shorter selection interval than can be achieved by other ports. A second port, Port B, services peripheral devices by means of the MIOP. Port B has a higher priority than Port C and will therefore be serviced first in a situation where both memory ports are receiving requests for service.

The MIOP provides independent control of data transfers between memory and peripheral devices by activating one or more device controllers attached to its signal bus. The basic MIOP contains eight subchannels each of which accommodates one device

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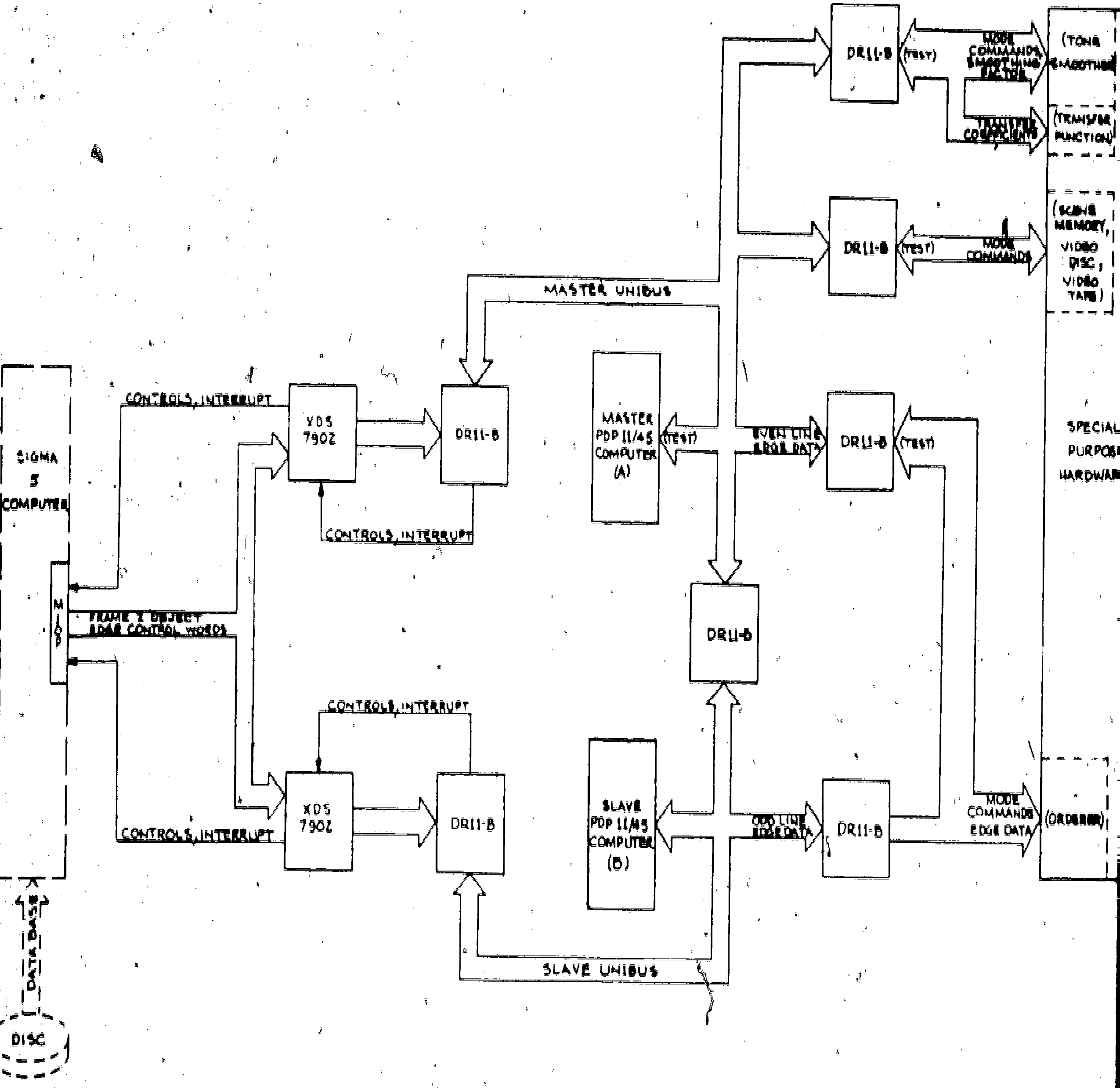

Figure 1. AEOSS System Block Diagram

controller. The MIOP can control and sequence the I/O operations of any number of its associated controllers simultaneously, allowing the CPU to concentrate on program execution. Any events which require CPU intervention are brought to the attention of the CPU by means of the interrupt system. The maximum combined data transfer rate of all device controllers operating simultaneously through one MIOP is approximately 400,000 bytes per second.

In order to interface the PDP 11/45 computers described in paragraph 2.3.1.2 to the existing STARS Sigma 5, additional equipment was added to the STARS facility. This additional equipment consisted of a second MIOP, three memory port expansion kits, and two device subcontrollers. The additional MIOP was required due to the heavy loading of the already existing MIOP. AFHRL also expanded the Sigma 5 core memory; thus, the need for three memory port expansion kits. Two device subcontrollers were added so that the Sigma 5 could communicate directly with both of the PDP 11/45 computers.

2.3.1.2 PDP 11/45 Computers—Two PDP 11/45 computers were procured by General Electric to supplement the computational capability of the Sigma 5 and reduce the per scene processing time. Each computer of Figure 1 consists of a central processor unit, a floating point processor, a DECwriter console, a programmer console, and a 4-level automatic priority interrupt. Computer A also has 64K of core memory, a 2.5 million byte disk cartridge drive and controller, a second disk drive with a non-removable, dual density disk, a dual floppy disk, and a 9-track magnetic tape transport and control unit. Computer B has 48K of core and a single floppy disk. The complete configuration also includes seven (7) DRII-B interface units configured as shown in Figure 1.

This minicomputer system is configured to allow direct communication between PDP computers, with the Sigma 5 computer, and to all special purpose hardware modules. A Sigma 5 independent operating mode is also possible wherein edge controls words are recorded on magnetic tape by the Sigma 5. The Sigma 5 edge control word tape, containing many frames of data, can then be transferred to the PDP magnetic tape unit and scenes can be generated without direct interfacing with the Sigma 5.

2.3.1.3 Special Purpose Logic and Recording Equipment—The special purpose logic and recording equipment and its points of interface to the PDP 11/45 computers are depicted in Figure 3. The computational functions implemented in special purpose logic consist of the orderer function, the video assembler function, two video combiner functions, an edge smoothing function and a sensor transfer function.

The orderer logic orders the element numbers corresponding to the projected data base edge intersections with each raster line into ascending numerical order. Up to 512 such intersections can be ordered for each raster line.

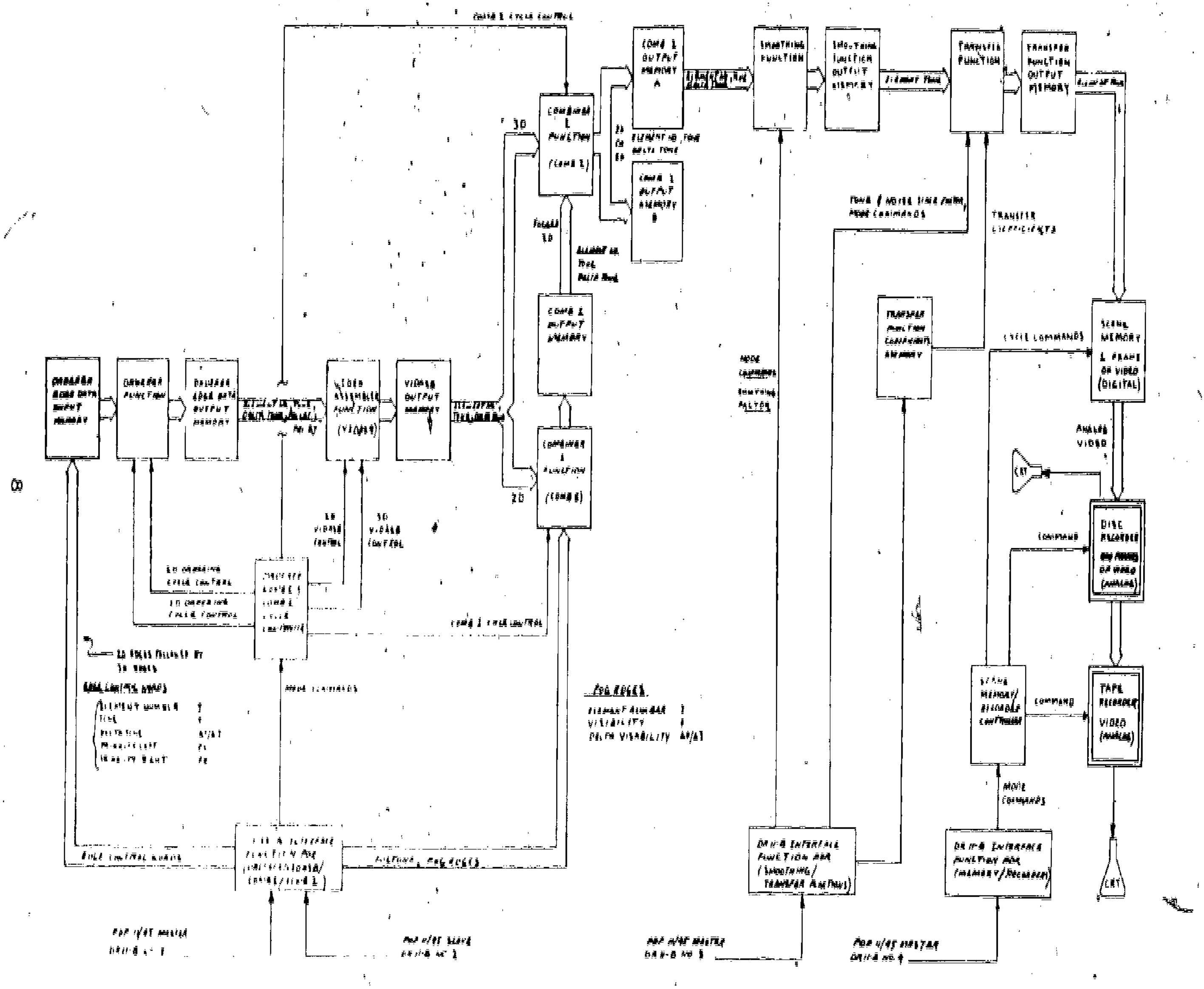

Figure 3. AEOSS Frame 3 Hardware, Block Diagram.

The video assembler logic receives the ordered edge intersections from the orderer logic, resolves priority conflicts, and outputs only the edge intersections which are visible within the scene. Prior to this point edge intersections observed by nearer objects must also be processed. Note that two-dimensional, three-dimensional, and fog edges are separately processed to this point.

The video combiner logic combines first the two-dimensional and fog edges, then adds the three dimensional edges, to end up with a single tone for each picture element. Thus at this point a complete CIG type picture (without edge smoothing) has been created.

If the system operator has selected edge smoothing, the raster lines and element numbers referred to in the preceding paragraphs are actually "sublines" and "subelements." That is, more raster lines and raster elements will have been computed than will ultimately be displayed. The edge smoothing logic accepts the data for the subelements on each subline (element number, tone, and delta tone) and generates smoothed data, free of staircasing effects for those raster lines to be ultimately displayed. Up to 16 sublines and subelements of smoothing can be specified by the operator.

The final stage of special logic is the sensor transfer function logic which applies a weighted matrix transfer function and sensor noise to simulate the transfer characteristics of the particular sensor being simulated. The final tone assigned to each element is thus computed based upon a weighted average of the tone of the element itself and the tones of up to 24 of its adjacent neighbors. Both the number of neighboring elements to be considered and the weight assigned to each element tone is specified by the operator. The operator can also specify the amount of sensor noise to be added to the video.

At this point, one raster line of video is complete and it is then loaded into the scene memory. The scene memory is a random-access semiconductor memory built by National Semiconductor. This memory is configured to store one complete frame (scene) of 8-bit, digital video data consisting of up to 480 raster lines of 640 elements per raster line. Thus, each picture element can be one of 256 grey shade levels.

Once a complete frame of video data has been written onto the scene memory, that scene is recorded on the video disk recorder and also displayed on the CRT. The video disk recorder thus accumulates consecutive frames of video data for subsequent playback in real time. The video disk used in this system is an Ampex Model MD-400 which utilizes a dual surface disk. Up to 600 tracks of data can be recorded where each track coincides with one frame of data. Playback at the standard TV rate of 30 frames/sec allows for up to a 20-second real-time sequence to be recorded before repeating. Each successive frame of data is precisely positioned with respect to the preceding frame such that a continuous sequence is perceived upon playback. The Ampex MD-400 can also display any single frame of data as a static scene from any scene recorded on the disk.

When dynamic sequences longer than 20 seconds are desired, such sequences are accumulated from consecutive 20-second sequences on a video tape recorder. The video tape recorder is an Ampex Model VPR-1. The VPR-1 is a precision device that allows near perfect matching of consecutive sequences to create longer sequences. Thus, any number (up to one hour of real-time video) of 20-second sequences can be transferred to the VPR-1 and precisely positioned with respect to the end of the last 20-minute sequence.

The entire recording sequence from scene memory through the video tape recorder is under the automatic control of a special controller which receives all its mode commands from the master PDP 11/45 computer. That is, no operator control is required beyond an initial selection of the number of frames of data to be recorded.

2.3.2 SENSOR SIMULATION SYSTEM OPERATION—Preceding paragraphs describe the sensor simulation equipment configuration along with a brief outline of the role of each equipment unit. The following paragraphs describe the detailed assignment of computational functions to the Sigma 5, the two PDP 11/45's and the special logic modules, including typical data flow for generating a single frame of video data.

2.3.2.1 Allocation of Functions—A detailed description of the various computational functions which are performed is contained in the system and software report prepared by General Electric under this contract. The various computational functions are grouped into general categories based upon the organization of real-time, visual computer image generation systems designed by General Electric, plus an additional category related to airborne electro-optical sensor simulation. These functional categories are labeled Frame I, II, III, and IV for simplicity. Frame I functions are those functions which must be performed once per frame time, and account for the scene-to-scene sensor motion and various coordinate system rotation calculations. Frame II functions are those calculations which are required to transform the numerical description of the data base to a set of edge control words which define the projection of the data base onto an imaginary view window. Frame III includes all remaining functions which must be performed to establish the color or gray shade of each picture element in the scene. Primary Frame III functions are video assembly, video combining, data ordering, and edge smoothing. The Frame IV functions are those unique to sensor simulation systems, and consist of the sensor transfer function, system noise, and related sensor system characteristics. With this categorization of functions in mind, the assignment of computational functions to the computational units can now be described.

To achieve the fastest possible per scene update rate consistent with a fully flexible design and reasonable cost, the pipeline processing technique (used most effectively in real-time simulation systems) was applied to the sensor simulation system design. With the pipeline processing technique, the complete set of computations required to develop a scene are assigned to separate, sequential processing units. Each scene is partially processed by the first computational unit, then the partially processed scene data is passed on to the next computational unit. While the second computational unit performs further processing on the first scene, the first computational unit begins processing the next scene. Any number of sequential processing units can be used, subject only to the number of simple divisions which can be made for the total scene computational task. For this sensor simulation system, two stages of pipeline processing were chosen with the first stage being the Sigma 5, and the two minicomputers and special purpose logic comprising the second stage of processing. It should be noted that the time to generate a single scene (and the first scene in a sequence of scenes) is the total additive time of each processing stage. Once the pipeline is filled (in this case it takes two consecutive scenes) however, a new complete scene is ready for display in the processing time of the slowest processing stage. The average scene update rate for a large number of sequential scenes therefore approaches the time used by the slowest stage of pipeline processing.

In this system, all Frame I and Frame II functions are assigned to the Sigma 5 computer. The existing Sigma programs were modified to provide more efficient execution by setting up larger core buffers, utilizing double buffering techniques to reduce disk accesses, and taking better advantage of scene statistics to minimize running time. The Frame III and Frame IV functions were divided between the special purpose logic and the two PDP 11/45 computers. The orderer, video assembler/combiner, and edge smoothing are Frame III functions assigned to hardware and the sensor noise and sensor transfer functions are Frame IV functions, also assigned to hardware. This hardware augmenting of the PDP 11/45's was essential in order to achieve reasonable scene update rates because of the time-consuming nature of these functions. It should be noted, however, that the flexibility of the simulation is maintained since these functions must be performed by any sensor simulation approach and the hardware is designed to be software programmable in terms of degree of smoothing, sensor transfer function, and amount of sensor noise.

It should also be noted that the two PDP 11/45's are configured to operate in parallel, performing exactly the same functions for different raster lines. One PDP operates on even raster lines while the second PDP operates on the odd raster lines. Thus, both parallel and pipeline processing techniques are utilized in this design.

2.3.2.2 Data Flow Sequence—Data flow through the system originates in the Sigma 5 computer. Processing begins with the reading and interpretation of the operator inputs which define the parameters controlling the scene to be generated. The Frame I functions are then performed by three separate software routines. The first routine generates the Scene Data Base file using the Extended Data Base file and the control parameters input by the operator. The Scene Data Base file contains information only for that portion of the Extended Data Base file that is within the field of view as defined by the operator input data. The Extended Data Base file contains all the information defining the complete gaming area data base as described in paragraph 2.2.1. As the Scene Data Base file is created, a list of the range from the selected viewpoint to each face of each object in the scene data base is also created. For three-dimensional cultural objects, the object centroid range is assigned to all faces of each object.

The next routine determines the relative priority of all the three-dimensional cultural objects within the field of view. For priority purposes, a three-dimensional cultural object is considered within the field of view if any portion of an encompassing sphere is within the field of view. For this purpose both an object centroid and object radius are defined as part of the Extended Data Base file.

The final Frame I routine generates a combined face priority list for all terrain and object faces within the field of view. This is accomplished by modifying the face range list generated earlier, such that the assigned range value for each three-dimensional cultural object (and all its faces) varies inversely with its relative priority. That is, the range values are forced to increase as relative priority decreases. In addition, the range value for each terrain face is forced to be greater than the range to any three-dimensional cultural objects that is superimposed on that terrain face. In this manner a range list is created, for all faces within the field of view, which varies inversely with the priority of the face in the event of priority conflicts. Finally this range list is ordered by increasing range to produce a unique priority number, based upon the position in the ordered list, for each face in the scene. This priority list is retained in memory for use by the Frame II routines in constructing Edge Control Words.

It should be noted that the creation of the combined face priority list required the development of a new algorithm for this program. The previous all software programs operated on an object priority basis rather than a face priority basis. For an object priority scheme to work, convex objects are required. Construction of convex objects to define terrain from DMAAC source data is not practical with automatic software techniques; thus, a new priority routine was required.

Once the priority list for all faces is complete, the Sigma 5 begins to execute the Frame II routines. These Frame II routines are the same routines implemented in the all software model, except that the routines were modified to operate on a face priority basis rather than an object priority basis. The output format of the Edge Control Words generated by the Frame II routines was also changed to be compatible with the 16-bit PDP 11/45 computers.

The input to the Frame II routines is the Scene Data Base and face priority list described earlier. In general, the Scene Data Base and priority list will remain the same for several consecutive frames, when the viewpoint moves very little between frames. Thus, provisions are made to allow the operator to specify the number of consecutive frames of Edge Control Words to be generated by Frame II before the Frame I calculations are updated. At the same time, parameters such as viewpoint, boresight, time of day, or any other control inputs can be specified to change at any particular frame or at every frame.

The Frame II routines generate an Edge Control Word for each edge of each face in the scene data base. These Edge Control Words consist of the projections of the data base edges to the image plane. Each edge is defined by the raster line and element

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number pairs at which its end point projections pierce the view plane, the slope of the edge projection, and various other data including face tones, priority, etc.

All data files used and created by the Sigma 5 Frame I and Frame II routines are maintained on the Sigma 5 disk. The Frame II Edge Control Word output file can be written on magnetic tape for later input to the PDP 11/45's or sent directly to the PDP's for Frame III processing.

The Frame III processing in the PDP computers is started by initializing the control parameters (from operator inputs) for the PDP edge generator routines and providing Edge Control Word data, either directly from the Sigma 5 or from magnetic tape. When the PDP 11/45's receive data directly from the Sigma 5, the two PDP's work in parallel to produce edge crossing data for each of their respective raster lines. The master PDP produces data for even-numbered raster lines, while the slave computer produces data for the odd-numbered raster lines. When Edge Control Word data is received from magnetic tape, the master PDP reads the data into its memory and then shares the data with the slave computer as they produce edge crossings for their respective raster lines.

The output of both computers is directed to the orderer function at the head of the hardware processor pipeline. The orderer logic alternately selects data from the two PDP's, thereby gathering data for all raster lines in the proper sequence. Thus, the two PDP computers accomplish the edge selection process, determine active edges, and compute edge data (element number, tone, and tone gradient) for each raster line in turn.

The orderer then arranges the edges in increasing element number sequence, and the video assembler resolves priority conflicts and outputs only actually visible edges. It provides for each, the element or subelement number at which the edge begins to control the tones on the raster line, the tone at that element, and the tonal gradient continuing along the line. In this manner the scene is processed on a picture-element-by-picture-element basis and assembled on a raster-line-by-raster-line basis. If edge smoothing is being applied, the assembled raster lines (sublines) are passed to the edge smoothing logic, then passed to the transfer function logic. The data from the edge smoothing logic is the data for picture elements and raster lines to be displayed. That is, the subelement and subline data have been used to generate smoothed data for the output raster lines and the subelement and subline data are then discarded. The data from the transfer function logic are output on a line-by-line basis, ready for display.

From this point, the completed raster lines are written directly onto the scene memory. The scene memory is configured to store a complete frame of data with 8 bits of video per picture element. Complete frames are assembled on a raster-line by raster-line basis in the scene memory, then the entire frame is transferred to the video disk. When the video disk is fully loaded with 600 frames of data, its contents are transferred to the video tape unit to create longer sequences.

As the Sigma 5 completes its processing of the first scene, it immediately begins to process the next scene such that at any given instant in time, two scenes are simultaneously being processed in the sensor simulation system. While the Sigma 5 works on one scene, the PDP's are processing the scene previously processed by the Sigma 5 and providing edge crossing data to the special purpose hardware logic. Thus, the two PDP's operate in parallel with one another, while the Sigma 5, the parallel PDP's, and the special purpose logic form a pipeline processor chain each performing a portion of the required scene processing.

2.3.2.3 Software Design—The all software routines implemented on the AFHRL STARS facility under an earlier contract, served as the basis for the current sensor simulation system software. These existing routines were reorganized in order to optimize execution time. By taking advantage of scene statistics, the average execution time for a scene was significantly improved. Since the algorithms were already known to be mathematically correct, the majority of the software effort was directed toward achieving more efficient operation. Some new routines/algorithms were developed to provide a face priority scheme and also to provide fading across individual faces of selected three-dimensional objects. Minor changes were also required in existing routines to accommodate the face priority approach.

Sigma 5 software consists primarily of the previous Frame I and Frame II software routines from the all software model. The Frame II routines have double buffering for all I/O operations such that software execution can proceed in parallel with the I/O operations once they have been initiated. Since a significant portion of the current Frame I and Frame II time is consumed in I/O operations, significant speed-up of execution time is achieved via this parallel organization.

All Sigma 5 software routines are written in the Fortran language, with the exception of special input/output routines which are written in assembly language. The decision to use Fortran was made to enhance the use and modification of the software by the users. Very little penalty in execution time resulted due to the efficiency of the Sigma Fortran compiler. In the case of I/O routines, however, the standard Fortran routines are necessarily very general purpose in nature and thus not efficient in performing specific and limited I/O tasks.

The software routines implemented on the PDP computers consist of previously developed Frame III edge generation routines. Of course, special routines were required to accommodate data exchanges between the Sigma and the PDP's, data output to the special purpose hardware, alternate raster line processing by the two PDP's, and to control the recording process.

As was the case with the Sigma software, all routines except special I/O routines, were written in the Fortran language. Double buffering of data files at both the input and the output of the PDP processing was also employed in order to overlay I/O time with processing time.

2.3.2.4 Hardware Design—The video disk, video tape unit, and the PDP computers and peripherals are provided with their own enclosures by the equipment vendors. Packaging of the CRT display, the scene memory and the special purpose hardware logic was provided by General Electric. The CRT and scene memory are mounted in one standard equipment rack and interfaced to other equipment units via General Electric designed cables and interface logic.

An additional equipment rack is required for the special purpose logic designed by General Electric. Design techniques and packaging are based upon the General Electric designs for real-time visual and radar simulation programs.

Physical and functional arrangement of the special purpose hardware within the equipment enclosures has been selected to meet the objectives of high reliability, easy maintenance and maximum utilization of space. The enclosures feature plug-in circuit boards, hinged card file assemblies, power supplies, power control devices and cooling air blowers.

Circuits used within the special purpose processing equipment are packaged on plug-in boards. The boards are approximately 5.5" × 9.75" in size with a design capacity of 40 integrated circuit devices and a 140 pin edge connector, of which 12 are pre-assigned for ground and power, leaving 128 available for signals. Extraction devices are provided on each board eliminating the need for special tools for insertion or removal. The circuit boards used are solderless wrapped boards of a universal design which lends itself to any circuit configuration by means of its capability of being solderless wrapped, either by machine or manually.

The circuit boards are plugged into a card file assembly, commonly called a "swing frame" because it is hinged on one side for access to the backplane wiring, and such devices that may be mounted behind the swing frame. The swing frame is composed of the circuit board guides which assure proper line up of the boards and their corresponding circuits; the backplane which contains all the circuit board connectors and their interconnections; and banks of cooling fans located top and bottom, to provide a continuous air flow during operation to all the circuit boards.

The principal part of the swing frame is the backplane. It is a two sided copper-clad epoxy glass laminate, which is precision machined to mount the board connectors and interconnections devices with sufficient accuracy to permit automatic wrapping. One side of the backplane serves as a power plane and the other as a ground plane. Power and ground connections are carried to all circuit boards by means of direct connections between board connectors and the planes. Power and ground is in turn carried to the swing frame by a dual set of flexible heavy duty cables which are inserted/ bolted to the backplane. Signals are carried to and from the backplane with zero-insertion force, lever actuated 96 pin connectors that are solderless wrapped to the circuit board connectors.

A coordinate system of row and column designators is used to identify each card slot; such information is prominently displayed on the face of the swing frame. To assist in properly inserting the circuit boards, decals are mounted on the face of the swing frame that list the circuit board slot and board identification code. The board identification code is printed on the ejector and thus is readily visible on all boards whether mounted or unmounted.

The enclosure used will accommodate up to two swing frames. The arrangement is such that full access to any circuit board is possible by opening the enclosure door. Filtered cooling air is drawn in through intakes located in the lower portion of the enclosure and discharged through perforated panels in the top, thus maintaining a positive pressure during equipment operation and minimizing dust accumulation within. Standard 120 volt, 60 cycle power is the only facility power utilized as logic power supplies are contained in the equipment rack.

3.0 RESULTS AND CONCLUSIONS

3.1 RESULTS

The results of this program can best be measured in terms of how well the objectives at the program outset are met by the system delivered. The objective was to develop and deliver a fast, nonreal-time sensor simulation image generation system with real-time dynamic playback capability to be usable by AFHRL as a research tool. The system was also to retain maximum flexibility to evaluate different algorithms, and provide the capability to create and record dynamic sequences for playback in real time.

In terms of these general objectives the program is an unqualified success. Results obtained during the test and evaluation phase have proven the flexibility of the system. The programmability of the functions implemented in hardware allows great latitude in evaluating different sensor characteristics and different edge smoothing implementations. The operator input parameters allow setup of any scene parameters desired and permit unconstrained selection of viewpoints within the data base. In addition, the capability is provided to bypass the hardware algorithms and replace those functions with any desired software algorithm, should even greater algorithm flexibility be desired.

Dynamic sequences have been recorded which demonstrate the ability of the system to create long dynamic sequences for playback in real time. Both the quality of the individual frames of video and the quality of the overall sequences have proven satisfactory for meeting the program objectives.

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The time required to generate complex scenes with high order transfer functions has been reduced by a factor of between sixty to one and ninety to one, depending upon the complexity of the selected scene, when compared to the all software model. The time penalty paid for high order edge smoothing has also been greatly reduced. It should be noted, however, that for a given scene the scene generation time is directly related to the order of edge smoothing selected. It should also be noted that the scene generation time is now completely independent of the transfer function applied.

In spite of the tremendous reduction in the time required to generate a frame of video, the specific design goal of 10 seconds or less for selected complex scenes was not reached. While many reasonably complex scenes can be generated in less than 10 seconds, an average scene generation time for scenes from the delivered data base is probably closer to 20 seconds.

In the early test and evaluation phase, scene generation times of up to several minutes were not uncommon. This led to an evaluation of where time was lost and how faster scene generation times could be achieved. The somewhat surprising result of this evaluation was that the major factor pacing scene generation time was the size of the core memory data buffers in the Sigma 5 and PDP computers. That is, the calculation time involved was at a satisfactory level and I/O transfer time was not a major factor. The real problem was the large number of data accesses required for complex scenes due to the size of the core memory buffers in relationship to the total data required to generate a complex scene. It was not that the buffers were small, but rather that the data requirements per scene were enormous. Once the problem was isolated, the obvious solution was to create larger buffers. Unfortunately all PDP core memory was already fully allocated to buffers and program storage. Thus, it was necessary to add additional core memory to the PDP configuration. By adding one additional 16k core memory module to one of the PDP computers and allocating all of the additional core to the edge control word buffers, a four-to-one reduction in scene generation time was achieved for selected complex scenes. Allocation of additional Sigma 5 core to the sensor simulation task also resulted in major speed-ups. While it would be possible to achieve still further reductions in scene generation time with still larger buffers, the practical limit has been reached. Use of more Sigma core would effectively eliminate all other Sigma processing tasks when the sensor simulation system is in operation. Addition of more PDP core to the system would require more core for both PDP computers and result in major changes in the PDP configuration to accommodate the additional core. The current scene generation time is not unreasonable for even the complex scenes and for the less complex scenes, no reduction in scene generation time would result from the use of larger buffers in any event.

In summary all major program objectives with the exception of the scene generation time were fully met by the system. The longer specific scene generation time does not detract from the overall system image generation performance, but simply requires more time for the generation of evaluation scenes.

3.2 CONCLUSIONS/RECOMMENDATIONS

It is recommended that future similar programs planned for heavy usage and requiring extensive computer resources be configured as stand-alone systems. The AFHRL STARS facility is required to support a large number of simulation activities. When the Sensor Simulation System is in operation, it requires such a large share of the STARS resources that efficient operation of other simulation programs is precluded.

A stand-alone sensor simulation system would either require more computing equipment at a higher cost, or require more time on a per-scene basis. If the slower per-scene computation time is acceptable, given the full-time availability of a stand-alone system, then a stand-alone system would actually be a lower cost system. Should the same per scene time goals be considered essential, the higher cost of the required general purpose computational equipment could still be partially offset. For example, the cost of integrating the STARS equipment and the sensor simulation equipment would not be incurred. This would save both manpower and equipment costs. It is also expected that operating costs would be lower by elimination of at least some of the requirements for premium time STARS operation.

Note that this recommendation should be considered only when existing computational equipment is heavily utilized or when the new program being planned will require extensive resources and usage of the existing equipment.

It is also recommended that a full complement of development peripherals be included with any general purpose computer system included in future simulation programs. Should such systems be configured as stand-alone systems, this is mandatory. Even when such a system is integrated with an existing computational system which includes development peripherals, however, any additional general purpose computing equipment should include development peripherals to support operation, diagnostics, and modifications to the system. The additional cost of such peripherals will be largely recovered through more efficient system operation.

For any computational system involving large quantities of data where data throughput is an important consideration, provisions must be made for large, high-speed data buffers. In such applications, data access time due to insufficient buffering can often be a major factor in data throughput. While computational speed and efficiency are the most important factors, when small quantities of data and repetitive calculations are involved, data access becomes equally important when large quantities of data are also involved. In such cases the use of small buffers, in an effort to minimize the cost of the computer system, should be implemented only when cost is the overriding consideration.

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