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COMPUTER IMAGE GENERATION: RECONFIGURABILITY AS A STRATEGY IN HIGH FIDELITY SPACE APPLICATIONS

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ABSTRACT

The demand for realistic, high fidelity, computer image generation systems to support space simulation is well established. However, as the number and diversity of space applications increase, the complexity and cost of computer image generation systems also increase. One strategy used to harmonize cost with varied requirements is establishment of a reconfigurable image generation system that can be adapted rapidly and easily to meet new and changing requirements.

This paper examines the reconfigurability strategy through the life cycle of system conception, specification, design, implementation, operation, and support for high fidelity computer image generation systems. The discussion is limited to those issues directly associated with reconfigurability and adaptability of a specialized scene generation system in a multi-faceted space applications environment. Examples and insights gained through the recent development and installation of the Improved Multi-function Scene Generation System at Johnson Space Center, Systems Engineering Simulator are reviewed and compared with current simulator industry practices.

The results are clear; the strategy of reconfigurability applied to space simulation requirements provides a viable path to supporting diverse applications with an adaptable computer image generation system.

INTRODUCTION

One of the key problems facing high fidelity visual simulation is balancing fidelity and realism with cost and versatility. Government and Industry Aerospace Engineering and Training disciplines have typically required the highest fidelity visual imagery to maximize research and training objectives[1] [2] [3]. In order to achieve the greatest measure of fidelity for the specified objectives, visual system contractors review specifications and configure specific systems to best meet the particular requirements of a given procurement. The resultant systems are tailored for specific engineering or training applications.

As the pace and diversity of space missions increase, and the requirements of space station construction and deployment come into sharper focus, the demands placed upon engineering and training visual simulation will escalate. In their 1987 IEEE paper[4] Robert H. St. John, Gerard J. Moorman, and Blaine W. Brown concluded "Simulation was important in the design and verification of the Space Shuttle, and it will continue to be instrumental in supporting changes and improvements to Space Shuttle hardware and software as well as to the mission design and verification process." Ankur R. Hajare, in a paper presented at the 10th Interservice/Industry Training Systems Conference[5], reviewed many of the requirements for the Space Station Training Facility. Continuing evidence of this need is underscored by the pending Shuttle Mission Training Facility visual system upgrade.

One strategy for harmonizing requirements with cost, while maintaining the highest level of visual fidelity, is to design and construct the primary image generation system components with versatility as a prerequisite. This versatility, or hereafter referred to as reconfigurability, applies to hardware, software, and data base elements, and permits timely reconfiguration of one or more of the system elements to meet a wide set of well defined requirements as well as new and/or additional requirements. This paper defines and addresses the significance of reconfigurability within the framework of the Improved Multi-function Scene Generation System recently installed at Johnson Space Center, Systems Engineering Simulator.

DEFINITION OF RECONFIGURABILITY

Reconfigurability, for the purposes of this paper, is defined as the capability to reorganize one or more components of an image generation system, including hardware, software, and data base components, to meet new, different, and/or expanded requirements. The methodology applied to identifying candidate components for reconfiguration is akin to the life cycle and development methodologies espoused by Dr. Roger Pressman[6]. He indicates "system definition is the first step of the planning phase and an element of the computer system engineering process . . . attention is focused on the system as a whole. Functions are allocated to hardware, software, and other system elements based on a preliminary understanding of requirements." Reconfigurability is a key additional requirement to be taken into consideration during the system definition phase. By identifying potential contributors to reconfigurability during the system definition phase, effort can be made to modularize and further refine these elements during the design and development phases. This, in turn, permits a smooth integration and implementation of these malleable components.

FUNDAMENTAL COMPONENTS OF AN IMAGE GENERATION SYSTEM

Before proceeding to identify specific image generation system components, it is necessary to review the fundamental components of an image generation system and provide some details about the Improved Multi-function Scene Generation System. (For a thorough review of image generation and processing theory see references and suggested reading[7] [8]).

As the block diagram in Figure 1 illustrates, the modeling system is the initial functional component of an image generation system. A characteristic modeling system hardware configuration includes a graphical workstation, a mini computer with mass storage and communication capability, and associated peripherals. The software components include a general purpose operating system complete with languages, text editors, and network capabilities, as well as the special purpose data base modeling software.

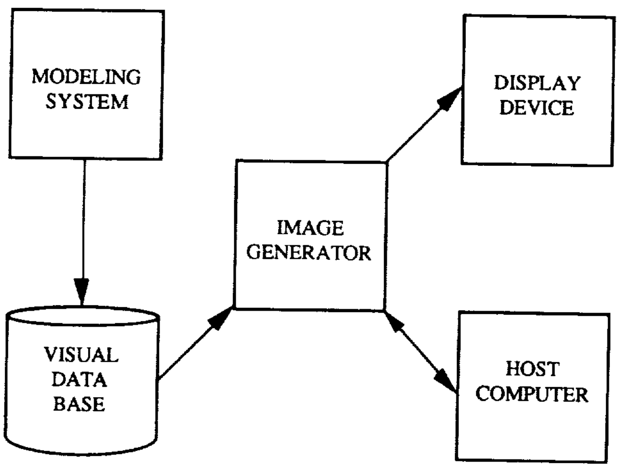

FIGURE 1
FUNDAMENTAL COMPONENTS OF AN IMAGE GENERATION SYSTEM

The modeling system is typically used in an off-line mode from the remainder of the image generation system. It facilitates the mathematical definition and construction of data base elements and organizes these elements into a visual data base (please note for the context of this paper, visual data base implies support of out-the-window or Closed Circuit Television (CCTV) views. This does not necessarily preclude other views including, but not limited to, infrared sensors or radar. For an introduction into the issues of data base correlation see references and suggested reading[9]). In addition to maintaining the mathematical representation of models and environment, the visual data base provides the framework for rapid and efficient access by the image generator.

The image generator (IG) is an highly specialized computer system typically consisting of a general purpose mini computer combined with multiple cabinets of custom image generation hardware. The hardware is controlled through a custom real time software (RTS) package that monitors IG performance as well as managing communication with the host computer.

The host computer maintains the mathematical model of the simulation, monitors operator input, and transmits position, attitude, and environmental control information to the image generator. The image generator, in turn, traverses the data base framework and displays the appropriate imagery on the display device.

THE IMPROVED MULTI-FUNCTION SCENE GENERATION SYSTEM

As the name implies, the Improved Multi-function Scene Generation System (IMSGS), an Evans & Sutherland CT6 System, installed at Johnson Space Center, Systems Engineering Simulator (SES) is dedicated to supporting many different aspects of high fidelity, large scale space simulations. The contract called for an image generation system that could integrate with existing SES simulation capabilities and augment the quality and quantity of visual imagery. Among other tasks, SES currently supports orbiter operational procedures development and testing, remote manipulator operations, payload handling, flight support and training on shuttle to proximity operations, docking and berthing techniques development, and conceptual development for the space station[10].

At the time of the CT6 installation, May 1988, the SES facilities included several networked Gould 32/87 host computer systems supporting an orbiter aft cockpit mock-up, an orbiter forward cockpit mock-up, a space station cupola mock-up, and a manned maneuvering unit (MMU) mock-up. The video feeding each of these mock-ups was derived from one of three image generation systems, each supplying one, or at most three, channels of imagery. The imagery was transmitted to the mock-ups through a sophisticated scene selection and video distribution system permitting allocation and assignment of an individual image generator channel to a specific view.

The IMSGS, as depicted in Figure 2, incorporates an Evans & Sutherland CT6 IG complete with a Gould 32/6781 mini computer. It is supplemented by a Digital Equipment Corporation MicroVAX based Modeling System complete with an Evans & Sutherland PS330 graphical workstation. The system also includes a maintenance and operation station and video switching and CCTV video post processing capabilities.

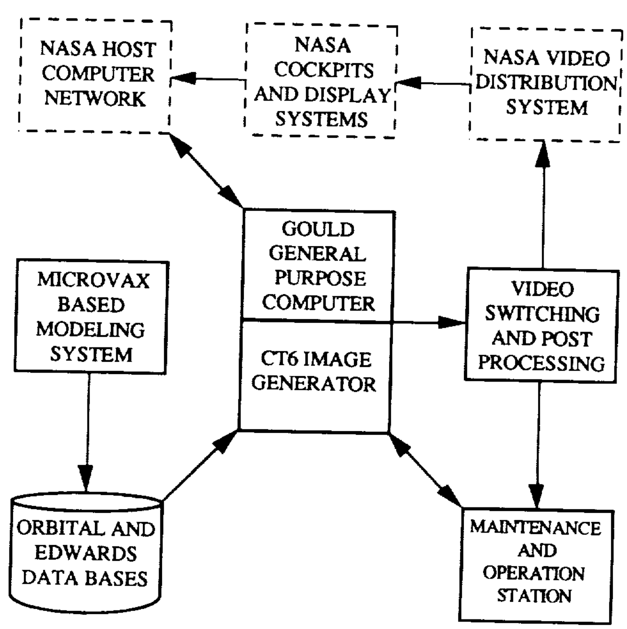

FIGURE 2
IMPROVED MULTI-FUNCTION SCENE GENERATION SYSTEM

The CT6 IG hardware supplies 6 channels of imagery. Each channel supports full texture capability and can display a standard capacity of 1500 polygons at 50 Hertz operation. Five of the six channels have a normal resolution capability of a half a million active pixels, while the sixth channel basic configuration supports three quarters of a million pixels. During terrestrial operations the hardware supports two fully independent eyepoints with up to six fields of view shared between the two eyepoints. During orbital operations each of the six hardware channels can function as a fully independent, six degree of freedom, eyepoint. One of the six channels is equipped with non-linear image mapping (NLIM) permitting pre-distortion of an image to correct for display distortions.

Acting as a front end for the CT6 IG, a Gould 32/6781 general purpose computer (GPC) system is networked to the SES host computer system and the IMSGS modeling system. With over nine hundred megabytes of disk storage, the GPC provides a repository for the visual data bases and sufficient storage space for operating system and application software needs.

During active simulations the GPC communicates with the SES host computer system at 80 millisecond intervals for position and attitude of the dynamic models as well as environmental data such as scene illumination level, sun angle, field of view, CCTV camera pan and tilt angles, and other control parameters. This information is transmitted to the IG for real time display.

When active simulations are not in session, the GPC supports stand alone simulations, diagnostic and maintenance activities on the IG, and general purpose software development. The GPC is equipped with the Gould MPX operating system, a custom real time software package supporting both host controlled and stand alone IG activity, and a comprehensive diagnostics software package to assist in fault isolation.

Assisting in both host controlled and stand alone modes, the IMSGS maintenance and operation station provides an interactive control console, or flybox, for monitoring IG activity, flying through data bases in stand alone mode, and for running diagnostics. The station houses dedicated monitors for each of the six image generator channels permitting simultaneous view of all image generator activity. There are also two dedicated CCTV monitors, one switchable CCTV monitor, and one switchable general purpose monitor.

The video supporting the maintenance and operation station is supplied via a software controlled video switching system. The video switching system controls distribution of video from the IG to the maintenance and operator station, cockpits, or to the video post processing hardware. The video post processing hardware can optionally convert RGB component video to PAL-I composite video for CCTV display, mix two channels of imagery for split screen CCTV, and overlay CCTV camera identification, pan angle, tilt angle, and camera temperature characters on the video for CCTV display.

The IMSGS modeling system supports definition, construction, modification, and display of CT6 visual data bases in an off-line mode. The modeling software includes the capability for creating new data bases, altering existing data bases, generating texture maps, automatic terrain generation from Defense Mapping Agency Terrain Elevation Data, and evaluation of IG performance through the use of a CT6 software simulator. The modeling system is connected to the GPC via an Ethernet interface, facilitating transmission of completed data bases.

A total of four operational data bases are supplied with the IMSGS. The first three data bases are orbital data bases containing the following common components: an earth model, a star field with 1,655 stars modeled with correct relative magnitudes and locations, a sun model, a moon model, and a highly detailed orbiter model.

In addition to the common elements, the first orbital data base also contains a detailed model of the Tethered Satellite Subsystem (TSS) complete with a pallet and satellite tower resting in the orbiter payload bay, and the satellite.

The second orbital data base contains a detailed and articulated model of the Remote Manipulator System (RMS) as well as a detailed model of the Hubble Space Telescope. The telescope model is visible in both stowed and deployed orientations.

The third orbital data base contains the detailed model of the RMS, a detailed model of the MB-9 version of the Space Station, a generic payload, and the Mobile Service Center (MSC) complete with a Mobile Remote Manipulator System (MRMS).

The fourth data base, a terrestrial data base, is the southern California region with a detailed representation of Edwards Air Force Base. The data base is 1,244 nautical miles by 1,244 nautical miles. The 121 nautical mile by 121 nautical mile terrain region centered about Edwards is map correlatable. Terrain elevation information was extracted from Defense Mapping Agency (DMA) Digital Terrain Elevation Data (DTED). In addition to the highly detailed Edwards AFB area, the data base is equipped with a detailed orbiter model and two detailed T-38 models.

Each of the aforementioned data bases make extensive use of algorithmic and photo-derived texture to augment scene fidelity and realism.

RECONFIGURABILITY, A CASE HISTORY

By the time the IMSGS contract was awarded in late September of 1986 the NASA Engineers who had specified the visual system requirements had already laid a great deal of the ground work for a reconfigurable image generation system. The requirements made clear the goal of reconfigurability in a number of areas, such as " the update rate shall be software selectable to run at 25, 30, 50, or 60 Hz" or "It is desirable that each channel be capable of having . . . a range of 0.25 to 1.0 megapixels . . . "(11).

The team of engineers assigned to the program, working with their NASA counterparts began the analysis, design, and implementation of the requirements specified in the contract. Some of the candidates for reconfigurability surfaced immediately, such as being able to redistribute IG hardware components to increase or decrease pixel resolution or polygon capacity. Other candidates have come to light further down stream such as the multi-tiered occultation solution. Specific examples of reconfigurable items are detailed in the following paragraphs, divided into three broad categories: hardware, software, and data base.

HARDWARE

There are numerous explicit requirements as well as suggested goals in the IMSGS contract[11] for hardware reconfigurability. Some of the more obvious items such as being able to increase memory or disk storage in the GPC or modeling system, or being able to attach other peripherals to the system, are not addressed in detail in this paper. The items deemed uncommon, or atypical, for image generation systems are detailed below.

Addressing the requirement for variable resolution, the CT6 image generator was equipped with the capability to share display processor components between channels. This permits increasing or decreasing the effective pixel resolution from 262,000 active pixels to over 1,000,000 active pixels by simply loading a different microcode initialization file. This also implies a variable line rate and pixel rate capability. The video line and pixel rates are programmable in ranges of 13 to 30 KHz and 10 to 40 MHz respectively, while the IG is equipped to run at 25, 30, 50, or 60 Hz, with display refresh rates of 50 or 60 Hz, thus allowing the use of a wide range of displays. The maintenance and operation station is equipped with multi-sync monitors able to match any line or pixel rate generated by the IG. This capability has already been put to use in the SES lab, matching the video characteristics of the old Conrac 62601 displays, as well as the newer XKD 1955 and SRL 2125 displays.

Just as display processor components can be shared between channels to focus pixel resolution, the geometric processor components can also be shared to focus polygon resolution. This permits an increase in polygon capacity from the basic 1250 polygons per channel at 60 Hz, to over 2,200 polygons per channel at 50 Hz operation.

As indicated earlier, the SES lab supports several cockpits each with a different number of displays. A sophisticated, software driven, scene selection system is in place that allows the assignment of any given image generation system channel to a particular display device in a particular cockpit. The IMSGS is required to interface with that system, and does so with the use of a software controlled video matrix switcher and video post processing capability. This video switcher can be controlled through local software commands within the IMSGS environment, or from the SES host computer system. Any one of the six CT6 channels can be routed through the switcher to provide an out-the-window, CCTV, or MMU view, as required, to any of the mock-ups.

One of the requirements of the contract stated that at least one IG channel be capable of supplying pre-distorted imagery at varying pixel resolutions for use on an unspecified display and/or projection system. This capability, known as non-linear image mapping, or NLIM, allows a digital mathematical correction of image components to ensure proper geometric relationships when displayed on a non-linear surface such as a dome. This capability works in harmony with the aforementioned display processor sharing to increase or decrease pixel resolution and is activated or deactivated through a microcode control file.

SOFTWARE

The software components identified as reconfigurable items were not as clearly defined at the requirements phase as the hardware elements, nor as straight forward to design or implement. There were the typical stated goals such as modularity and maintaining reserve capacity for future growth. There were also the not-so-obvious goals of identification and reutilization of key individual modules to help meet future requirements, or documenting critical portions of code to such a degree that a novice software engineer, with little or no image generation system background, could effectively learn and modify the software on an as needed basis. Through striving to meet these and other stated and unstated goals there were several software items that surfaced and were implemented as key reconfigurable elements.

One of the key reconfigurable software elements is a portion of the real time software package known as occultation management. This software works in harmony with the data base fixed priority relationships and existing real time object range sorting algorithms to provide an additional tier of object level occultation management. This is one of the areas where the software has purposely been designed and documented to facilitate a shopping cart approach to new requirements. By using off-the-shelf key modules and, where necessary, modifying modules that are similar in nature to the additional element(s), new capabilities can be added in a timely and consistent manner.

In like manner, the host to GPC interface communications software is designed to allow the timely addition, or deletion, of simulation control parameters. In typical simulation applications a fixed number of computer words are reserved for data communications between the host computer system and the image generation system, where each word, byte, and bit have a known fixed location and format in the data buffer. Changing the fixed format to add or delete a parameter requires modification of all software elements on both sides of the interface accessing that data buffer. By contrast, the reconfigurable solution packetizes or modularizes each control parameter by parameter type. For example, all dynamic model position and attitude data is identical in type and format, only the model identification bits vary from model to model. Adding a new model to a simulation is achieved by simply adding that packet of information to the communications block. The block is fixed length in nature, but the parameter packets can vary in any number and sequence within the data block. When new packet types are defined, an additional module is added to the communications software to handle that packet type, with no adjustments or adverse affect on other packet modules.

Similar to the concept of packetizing the control information above, the diagnostics software is organized in a modular fashion. Rather than writing a package of diagnostics unique to each image generation system configuration, or each backpanel within the image generation system, IMSGS uses a general purpose diagnostics interpreter for fault isolation within the IG. A diagnostic test is provided in the interpretive language for each applicable card type in the system. By interactively, or through a batch file, instructing the interpreter which card, function, backpanel, channel, or system to test, the appropriate diagnostics are executed within the framework established by the operator. If a particular situation demands a modification to a diagnostic, the particular diagnostic can be edited with a normal text editor to include the additional capability.

DATA BASE

As with the majority of hardware reconfigurable components, most data base components were readily identified through specific requirements in the contract. The obvious items surfaced immediately and included such elements as: a general purpose shuttle model with variations supporting attachment of an RMS, articulated doors and solar panels, and a docking tunnel; an earth model complete with cloud cover and an atmosphere ring; dynamic moon and sun models; a star field containing a minimum of 100 specific stars with correct relative magnitudes and locations; two specific payloads including the Tethered Satellite Subsystem and the Hubble Space Telescope with variations for stowed and deployed positions; and the MB-9 version of the space station including articulated solar arrays, a highly detailed primary docking port, and a dynamic mobile service center with MRMS.

Comparable with the software items there were reconfigurable data base components that surfaced during the design and development phases as well. For example, one generic CCTV model was created and referenced for each of the shuttle, RMS, and MRMS CCTV locations; one grapple fixture model was created and referenced for the two space telescope grapple fixtures, the shuttle grapple fixture, and the space station grapple fixture; one v-guide model was created and referenced for each of the three locations in the payload bay; one set of visual approach slope indicator (VASI) lights, ball bar lights, and precision approach path indicator (PAPI) lights were created and referenced for each applicable runway at Edwards Air Force Base.

Each of these data base components, along with many others, are available on the IMSGS modeling system to allow modification of existing data bases or construct new data bases in order to meet new or expanded requirements. SES has already begun utilizing many of these components to implement the Infrared Background Signature Survey (IBSS) and Orbital Maneuvering Vehicle (OMV) simulations not specified in the IMSGS contract.

CONCLUSION

Throughout the project life cycle there have been several key items identified as reconfigurable in nature. Many of these items were identified as specific requirements in the contract, some of the items were already embodied in various combinations of hardware, software, or data base, and some of the items surfaced while in the design or development phase. In all cases it was evident that if a particular item had been anticipated and identified during either the requirement or system definition phase, it was cheaper in terms of raw cost and schedule to implement than if it was identified later in the life cycle. Even when items were identified late in the contract, it was still beneficial in the long run to either include them as part of the contract, or recommend them for inclusion at a later date. Also, in all cases, once a given item was implemented, the savings in exercising the feature in terms of time, fidelity, maintainability, and development cost was obvious. The IMSGS is providing SES with a truly reconfigurable scene generation system that can grow and adapt with their new and changing requirements.

In an industry where change and redefinition are the norm, reconfigurability provides an important implementation and budget control strategy to assist in large scale space simulations. In order to be most effective, the reconfigurability strategy requires significant forethought and planning at the earliest phases of definition. Anticipation of expanded capabilities in performance, fidelity, and implementations can greatly enhance the systems potential. The results are clear, the strategy of reconfigurability applied to space simulation requirements provide a viable path to supporting diverse applications with an adaptable computer image generation system.

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