ADVANCED GRAPHICS PROCESSOR*

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ABSTRACT

This paper describes cockpit display processor research and development being conducted at the Wright Laboratory. The objective is a compact, high performance, cockpit avionic display generator. The resulting system will generate 1.5 million triangles per second and manipulate high resolution video. The design is based on a pipeline of custom VLSI geometry processors and smart memory. The application of this advanced system is to enhance the situational awareness of pilots flying tactical fighters. However, the WL graphics processor design will be available to the tri-services and NASA.

EVOLUTION OF COCKPIT DISPLAYS

The key to victory in air combat is the pilot's awareness of the tactical situation. Specific concerns include the location and activity of both friendly and enemy forces as well as ownship position, status and offensive/defensive options. In the early years of military aviation, the pilot obtained sufficient tactical information by simply looking out the cockpit window. In that era a threat had to be within visual range to pose any sort of danger. As airborne weapons evolved from guns to long range missiles, the effective distance and airspace a pilot had to be concerned with increased significantly. It became necessary to know the position and intent of objects beyond visual range. Radar was integrated into the aircraft providing the pilot with an electronic display on which to detect and monitor these long range targets. A similar system was developed to warn the pilot when his own aircraft was detected by an enemy radar. Using this configuration his attention was divided between the view outside the cockpit, the radar display, and the electronic warfare display.

As weapons and aerial warfare continued to evolve, many complicated systems were added to the cockpit to detect different kinds of targets, both on the ground and in the air, to aid in navigation, provide command and control functions, and maintain communications. Each system brought a new set of sensors and often a separate display with a unique format and scale. These systems were developed individually at various points in time by many different design and upgrade programs. The focus of each new effort was on providing a specific capability. Little regard was given to interoperability, integration, or even similarity.

In spite of the advanced capabilities provided by these systems, or more appropriately because of them, the pilot workload in today's top end tactical fighter aircraft is approaching the limits of human capability. Multifunction displays, classic "steam gauge" dials and indicators spread throughout the cockpit provide data in scales, ranges, and formats which differ from display to display. The diverse set of data must be mentally fused by the pilot in order to achieve a single, integrated assessment of the tactical situation. This complex task must be performed in combat prior to making a life or death decision.

PCCADS

With the emergence of electronic displays, the notion of integrating information from multiple sensors into a single, composite display became feasible. The question foremost in the minds of cockpit designers was how to simplify the vast amounts of data into an intuitive and compact presentation. The McDonnell Douglas Corporation, under contract to the Air Force Cockpit Integration Office, conducted a study which implemented large area, high pixel count, integrated displays and composite graphics in a cockpit simulation. The Panoramic Cockpit Control and Display System (PCCADS) study was carried out in two phases,

PCCADS 2000 - a near term solution; and PCCADS 2001 - a solution for the next century [1]. The simulations were ground based so weight, power, and space were not a factor. Cathode ray tube displays, high power graphics workstations and local area networks were used to generate tactical displays which were compared against the F-15E head down display (HDD).

In PCCADS 2000, researchers explored the utility of techniques which would be obtainable in tactical fighters by 1995. The PCCADS cockpit was configured with a 10 x 10 HDD which displayed the same information and format as that provided by the 6 x 6 inch, F-15E HDD. The only difference was that the PCCADS HDD displayed the information in a larger format while maintaining the same resolution. The result was an increase of 28% in the pilot's kill ratio.

The process is already underway to implement flat panel displays into the cockpit [2]. This technology is very mature and on the verge of mass production. Flat panel displays provide a large, high resolution viewing surface where composite images can be presented with complex graphics at a scale which is readable. In addition, they replace the CRT displays which are difficult to maintain due to high voltage operation, and which take up a considerable amount of space, weight, and power. However, to utilize the millions of available pixels, a much more powerful processor must be developed.

PCCADS 2001 investigated technology which will be available in the cockpit by the year 2000. The cockpit simulation was configured with two 10 x 10 inch displays and one 4 x 4 inch display. The smaller panel was used to present secondary information while the large HDD was used to present composite images of integrated sensor information in multiple, user defined windows. This research demonstrated the payoff in increased situational awareness from integrating data into information and displaying a "big picture" graphic to the pilot on one large tactical display.

ADVANCED GRAPHICS SOLUTIONS

Recent Air Force research has identified technologies in addition to those investigated in PCCADS which also significantly improve a pilot's effectiveness. Specific concepts under investigation include manipulation and integration of high resolution sensor video data and digital terrain maps, advanced visual cueing methods, and three dimensional perspective display formats.

Three dimensional viewing is more intuitive to the human visual system and conveys more information than

two dimensional graphics. Such a perspective gives the pilot a better feel for the relative orientation of his aircraft and external objects under surveillance. In addition, objects such as the threat envelope of surface-to-air missiles could be displayed in three dimensional perspective to help the pilot avoid the weapon system's kill area.

Another useful capability is the display of high resolution video from imaging sensors such as FLIR, LLTV and SAR. Such sensors provide a much more information than is currently available using low resolution displays. This gain in resolution increases targeting accuracy for visually controlled systems especially when operating at night and in adverse weather conditions.

The ability to display and manipulate digital terrain maps would greatly enhance situational awareness. Graphics symbology can be generated and overlaid on digital maps to clearly define the pilot's position, the position of aircraft, friend or foe, and the terrain and target position relative to him. Geographical features could be presented in a more intuitive "god's eye view" perspective, looking down at the terrain, or from the pilot's point of view.

Full color and visual cueing (light source calculations and shading) provide for a more intuitive interface that again takes advantage of the processing power of the human visual system. Color coding is a must to provide a larger information bandwidth in which to separate the various objects which must be displayed to remain in full control of the combat arena.

Succinctly put cockpit display designers are exploring the following advances in graphics presentation:

1. Increase the size and resolution of current display devices.
2. Provide full color graphics with sophisticated lighting, shading, hidden surface removal and transparency.
3. Provide three dimensional perspective.
4. Apply preprocessing to data to fuse individual sources into composite displays.

DEMANDS ON THE GRAPHICS PROCESSOR

The performance of graphics processors has traditionally been constrained by three technological bottlenecks [3]:

Table I Performance Requirements
(MVEPS - Million Vectors Per Second , MPIPS - Million Pixels Per Second)

GRAPHICS CAPABILITY	FUNCTIONAL REQUIREMENT	PERFORMANCE REQUIREMENT
2-D Characters & Vectors	2-D RENDERER 1 MVEPS Anti-aliased, Hi-Res Video	10 MIPS 100 MPIPS 10:1 Data Compression HDD / HDTV
3-D Perspective View	3-D RENDERER 500K Polygons / s Realistic Lighting Z-buffering Texture Mapping	200 MFLOPS Geometry Transform Engine 1.5 MPIPS Fill Rate 1.5 - 2.5 GOPS
Sensor Video	VIDEO PROCESSOR Rotate, Translate, scale High Resolution Video	30 MPIPS 240 MIPS
System Control	DATA SERVER Reconfigurability PHIGS Server Window Manager	(i960) 25 MIPS, 10 - 17 MFLOPS (PHIGS Engine) 100 MIPS, 20 MFLOPS

1. The video memory access rate
2. The number of integer operations which can be performed per second
3. The number of floating point operations which can be performed per second.

Increasing the performance requirements of the graphics generator will greatly exacerbate these problems. For instance, increasing the size of the display while maintaining 100 pixels per inch resolution causes a tremendous increase in the number of memory accesses which must be maintained at refresh rates in order to update millions of pixels. A 1280 x 1024 pixel display in each eye of a head mounted display system results in trying to access 2.6 million memory addresses, more

than 60 times per second. Sophisticated pipeline or parallel techniques must be developed to achieve these speeds with available memory bandwidth constraints. Rendering integrated graphics will require complicated display structures which generate hundreds of thousands of polygons and require tens of millions of instructions per second to edit and traverse. Providing visual cues to the pilot with realistic lighting, shading and three dimensional perspectives of these large polygonal renderings will require tens of millions of floating point operations per second. These requirements are translated to computer operations in Table 1.

Implementing the proposed techniques with existing avionic graphics processors is simply not possible. The most sophisticated processor currently flying is the F-15E's MPDP (multipurpose display processor). This

Figure 1 Cockpit Avionics Graphics Processor Program

system is a highly optimized vector generator. The software is platform specific and is written in custom macros and assembly language. While the system performs extremely well in its current role, the operating speed of the processor can not be accelerated enough to update the equivalent of 100 million pixels per second or more nor can it refresh the hundreds of thousands of vectors necessary to represent complex images.

The given requirements are more characteristic of high end, graphics workstations than for avionics based systems. Systems such as the Ardent Titan or the Stellar GS 1000 can generate between 100,000 and 200,000 fully processed polygons per second. A Silicon Graphics can generate more than 1 million polygons per second; however, the system is very large, very heavy and cannot easily be supported by a fighter avionics architecture. Even the minimal hardware configuration for these workstations is much too large. A new architecture, much smaller in size but with workstation performance must be developed to satisfy the graphics needs of twenty first century cockpits.

COCKPIT AVIONICS GRAPHICS PROCESSOR (CAGP)

Wright Laboratory is currently conducting a research and development effort to acquire an advanced, cockpit avionics, graphics processor. The basic goal of the program is to develop a graphics system with the power of high end workstations but in a package which meets the constraints imposed by the avionics environment.

The primary requirements for the processor are:

1. Generate 1.6 million lighted, clipped, z-buffered, anti-aliased triangles per second.
2. Accommodate many different display formats including analog and digital video, 3-D objects, 2-D objects, raster and vector graphics generation and prerendered images such as digital terrain maps.
3. Fulfill avionics architecture constraints on power weight, space, fault tolerance and graceful degradation.
4. Meet military specifications for reliability and maintainability.

The CAGP program consists of several large projects. These efforts include the Graphics Processor Definition (GPD) which has been completed, the Cockpit Display Generator (CDG) project, potentially the Cockpit Graphics Software Architecture (CGSA), and various in-house simulation and modelling projects. Figure 1 shows the status and chronology of each project.

GRAPHICS PROCESSOR DEFINITION

The Graphics Processor Definition project was a contract with the Honeywell System Research Center to define the top level architecture and computational requirements of an advanced avionics graphics processor capable of generating the display formats developed in PCCADS [4]. The results of that effort are documented in a VHSIC Hardware Description Language (VHDL) performance model. This model simulates the system wide latency of the proposed architecture and allows design tradeoffs to be made to detect and eliminate performance bottlenecks.

The software defined in GPD for the CAGP comprises an operating system, a graphics application and a PHIGS (Programmer's Hierarchical Interactive Graphics System) kernel. The operating system is to provide overall control to the graphics pipeline and interface to other avionics systems via the PI-Bus. The graphics application is to define and generate custom display formats for a particular platform or mission. Finally, the PHIGS kernel is to provide the underlying graphics structure creation, editing and manipulation capability. The operating system and PHIGS kernel is a one time development

effort; however a library of application software will eventually be written to satisfy the many variables which are mission or platform dependent.

The hardware defined in GPD consists of the data server, a video processor, a 3-D pipeline and a 2-D channel. The data server is to host the operating system and provide command and control for the graphics pipeline. This general purpose processor is to communicate with other portions of the avionics suite including the user interface devices and displays. If a fault is detected in any graphics component the data server is to reconfigure the graphics pipeline to provide graceful degradation and fault tolerance. The display list traversal engine is also located on the data server card. This ASIC is to host the PHIGS graphics kernel and generate the primitives which are used by the rendering modules.

The video processor is to receive sensor video and digital map data via the PI-Bus and is to be controlled by the data server. The video processor is to provide synchronization for multiple video sources and perform translation, rotation and scaling to generate a format suitable for creating composite display in the video merging modules.

The 3-D pipeline is to meet the size, weight and power constraints of an avionics architecture while providing the 3-D perspective display of a high end graphics workstation. The polygon generator is based on a modified Pixel Planes 5 processor developed at the University of North Carolina, Chapel Hill [5]. PHIGS primitives are to be fed to the 3-D pipeline from the traversal engine. These primitives are first processed in the geometry engines where they are to be clipped, lighted, and transformed to world coordinates. The transformed primitives are then to be rendered in parallel using the processor enhanced memory.

The 2-D channel is to generate two dimensional text, icons and conics and merge them with images from different sources such as FLIR, SAR, and digital maps. This module also contains a vector generator to provide compatibility with current display generators.

COCKPIT DISPLAY GENERATOR

Honeywell is presently involved in a contract to develop detailed designs of the architecture defined in GPD. This CDG (Cockpit Display Generator) effort will result in a system specification document and more importantly, a functional VHDL model of the Video

Processor, the Data Server, the 3-D pipeline and the 2-D channel [6]. This functional model will be used to validate the architecture. The models will then be synthesized to provide the ASIC descriptions in a form which can be delivered to a foundry for fabrication.

COCKPIT GRAPHICS SOFTWARE ARCHITECTURE

The Cockpit Graphics Software Architecture (CGSA) effort extends the Domain Specific Software Architecture to cockpit graphics [7]. The cockpit graphics domain will be analyzed to identify reference architectures and common components which can be used to populate a library of reusable software components specific to cockpit display format design. Tools will be developed to automate the design of graphics applications allowing display designers to make use of the reference architecture and common software modules. These tools will provide a significant reduction in the total life cycle cost of the CAGP since each application must otherwise be custom developed for each platform and optimized for a particular mission. A large portion of each application can be "mega-programmed" by utilizing the reusable code modules available through the CGSA tools. In addition, this tool set provides a common interface between display format designers and software programmers.

IN-HOUSE RESEARCH

In addition to the design effort Wright Laboratory is conducting internal research and development. The goals of this research are 1) to establish a top down design approach for avionics architectures and components using VHDL to both capture and validate the design from requirements analysis to pre-fabrication and 2) to develop VHDL models of an avionics suite which can be used as a test bench for future design and development efforts. Several projects (see figure 2) have been established to accomplish these goals. These projects include researchers from the Ohio State University, the University of Cincinnati, and the Cockpit Avionics Office.

The Ohio State University is developing a VHDL model of the Intel i960 processor which will be used to implement the graphics processor data server [8]. This model is unique in that it is capable of executing the software which will eventually control the data server ASIC.

The University of Cincinnati is developing a distributed simulation which will provide the capability to execute

Figure 2 Distributed VHDL Simulation

large simulations containing many VHDL models over a large computer network [9]. This capability is essential as simulations grow beyond the confines of a single workstation. This environment will provide the capability to migrate processes from one workstation to another during execution without loss of simulation time.

The Cockpit Avionics in house team is acquiring and/or developing VHDL models of the JIAWG avionics suite. Functional models of the High Speed Data Bus, the PI Bus and the TM Bus will be integrated into a functional model of the essential JIAWG avionics modules [10]. The i960 processor model will be folded into the JIAWG architecture model to provide an avionics test bench capable of executing Ada operating system and graphics application code. This test bench will be used to evaluate the Honeywell Cockpit Display Generator VHDL models as well as any future systems developed in VHDL for use on the JIAWG architecture.

SUMMARY

The Wright Laboratory is designing a graphics processor with the equivalent of high end graphics workstation performance in an avionics package. The application of this graphics generator is to enhance the situational awareness of pilots in tactical fighter aircraft. The resulting combination of large area, high resolution displays driven by a high performance processor meeting the rigid constraints of an avionics system is directly

applicable to all faucets of the aviation industry, both commercial and military. In addition the VHDL distributed simulation of a JIAWG avionics suite will be available to the tri-services and NASA as a test bench for future graphics processor architectures as well as other systems developed using the PAVE PILLAR/PAVE PACE architecture. Finally the custom VLSI components developed in this effort have a number of applications in both DOD and NASA applications as well as commercial graphics implementations either airborne or ground based.

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