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Survey of Currently Available High-Resolution Raster Graphics Systems

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Abstract

This paper presents data obtained on high-resolution raster graphics engines that are currently available on the market. The data were obtained through survey responses received from various vendors and also from product literature. The questionnaire developed for this survey was basically a list of characteristics desired in a high-performance color raster graphics system which could perform real-time aircraft simulations. Several vendors responded to the survey, with most reporting on their most advanced high-performance, high-resolution raster graphics engine.

Introduction

Electronic display generation systems are presently being used for airborne crew station displays.[1] The purpose of these display generators is to receive information from other aircraft systems and process this information to produce displays on monitors and other types of display media. There are two basic types of display generators available for this application: calligraphic and raster graphic.

Calligraphic, or stroke, systems produce displays by drawing lines between given end points. With this vector drawing process, the electron beam of the system traces the exact shape of an image onto the cathode-ray tube (CRT) screen. As a result, generated displays have a rather skeletal appearance (see fig. 1). Stroke drawing would be well suited for a maplike navigational display, but because of the inability to do shading, it is unable to produce realistic visual scenes that may be necessary for other situations. Stroke systems contain much simpler circuitry than raster generators. The mixing of computer-generated displays with raster aircraft imaging sensor data, like that from radar, may be desired; however, it is difficult to mix a stroke-drawn image with a raster image.

Raster graphic systems have the ability to produce synthesized vectors as well as text and solid shaded areas. Figure 2 gives an example of a raster-generated primary flight display. Each time the CRT is updated, the entire surface of the screen is redrawn (refreshed). During this refresh cycle, the electron beam traces the screen on a row-by-row basis from left to right and top to bottom. This form of display generation has the capability of producing realistic synthetic visual scenes that may have potential for low-visibility landing situations. Raster systems also provide an easy means of mixing display symbology with outputs from aircraft imaging sensors. Although raster graphics systems require more complex circuitry than stroke machines, the size and cost of rapidly advancing microcircuit and microprocessor technology continue to decrease, making raster graphic generators even more attractive for use in aerospace crew stations of the future.

This paper focuses on the use of raster graphic technology for aerospace research, with a view that recent advances in commercial equipment can, at a later date, be incorporated in flight hardware in aerospace crew workstations. Data obtained from a survey of currently available high-resolution raster graphics engines are presented. Raster graphics is defined along with various components of a raster graphics system. The various display generators are categorized according to their main processing dependency, with tables presenting the surveyed data for each category. Most of the systems surveyed are high-resolution, high-performance, real-time raster display generators.

Raster Graphics

Raster graphics is a form of computer graphics which permits the display of synthesized vectors, as well as text and solid shaded areas. Graphic objects are stored in the display memory as data for each point or picture element (pixel) that composes the object. These bits of data are mapped into display memory addresses that have a one-to-one correspondence to pixel locations on the monitor screen (see fig. 3). This type of memory, known as bit-mapped display memory, is, therefore, conceptually arranged as a two-dimensional array corresponding to the raster of the monitor. The raster is a matrix of pixels which covers the entire surface of the screen. Each horizontal line of pixels in the raster is referred to as a "raster line" (refs. 1 and 2).

The graphic image is drawn on the monitor screen by a sequential raster scan of the display memory. This is done on a row-by-row basis where the top row of memory is the first scan line, etc. The process of drawing one entire screen of information is referred to as the "refresh cycle" (refs. 1 and 2).

Although the raster scan method of drawing can produce solid shaded objects, certain techniques may be necessary to enhance the quality of the displayed image. Antialiasing is the process of smoothing aliased or "jaggie" lines that are produced by a raster system when drawing vectors that deviate from the horizontal and vertical (see fig. 4). Antialiasing is achieved by a shading of the vector edges with the background color. There are various antialiasing algorithms in existence, all of which are effective to

[1] Jack J. Hatfield, Langley Research Center, presented a tutorial on Crew Station Technology at the AIAA/IEEE 5th Digital Avionics System Conference, Oct. 31, 1983.

some degree in smoothing aliased lines. A nonaesthetic concern is the effect antialiasing has on the update rate of the display. If antialiasing is performed by hardware methods, the update rate should be affected only minimally. One other technique that helps minimize the detectability of aliased vectors is the use of a higher resolution generator and monitor. Using this higher resolution hardware makes the "jaggies" smaller and, therefore, less perceptible to the human eye at a given distance.

Details of various aspects of a raster graphics system are discussed in the next section.

Characteristics Surveyed

The questionnaire developed for this survey was designed to obtain information on high-performance color raster graphic display generators for use in real-time aircraft simulations. The following is a brief description of the characteristics contained in the questionnaire. These characteristics are included in comparison tables that follow. Table I presents the abbreviations used to represent the characteristics in the comparison tables, tables II and III.

Model

The models listed are the products that were surveyed from the indicated vendors. Only the high-performance color raster systems were considered.

Cost

The cost estimates shown in tables II and III are baseline list prices. Any options would result in an additional charge. Most vendors also offer a discount to government agencies.

Processor Type

A graphics system contains two separate processors. The central processing unit (CPU) is the center of computer activity. It performs essential data manipulations and supervises the operation of the computer system as a whole. The display processing unit (DPU) can be considered a special-purpose CPU. It interprets commands to display graphic objects on the display device (ref. 2).

The majority of the stand-alone workstations surveyed use the Motorola MC68020 microprocessor as the basis for the CPU. The MC68020 is a 32-bit microprocessor that has provisions for coprocessing. The processing power of this microprocessor is comparable to that of today's more advanced minicomputers and even those of many mainframe machines (ref. 3).

Advanced Micro Devices microprocessors were most often used as the basis for the DPU of the surveyed equipment. The following microprocessors were most common: AMD 2901, AMD 2903, and the AMD 29116. The AMD 2901 is a 4-bit bipolar bit-slice microprocessor that can perform three binary arithmetic and five logical operations. The AMD 2903 is also a 4-bit bipolar bit-slice microprocessor. It can perform all the functions of the 2901 with additional functions included that are particularly useful in arithmetic-oriented microprogrammed systems. The AMD 29116 is a 16-bit bipolar microprocessor that contains several special purpose instructions and is specified to operate at a 100-nsec microcycle time (ref. 4).

Some of the surveyed systems include proprietary microprocessors which could not be disclosed. Others depend on a host processor and do not have a self-contained CPU.

Word Length

The word lengths for the CPU and DPU are given in the comparison tables. A larger word length allows, for instance, more computer instructions or operations to be encoded in fewer words, resulting in a faster processing time. The CPU word length does not apply to those systems that depend on a host processor.

Display Memory

The display memory (also known as refresh buffer, frame buffer, or bit map) contains the information necessary to generate the signal which places an image on the monitor screen. This quick-access memory stores information for every pixel in the raster. Most graphics systems have a display memory that is much larger than that required to generate one screen of information. A double-sized memory allows one frame of data to be drawn while the other is being updated, thus avoiding refreshes of incomplete images. This technique is known as double buffering. An expanded display memory also permits the programmer to scroll data vertically or pan it horizontally and even have different images located in separate areas of memory for quick access (ref. 1).

Mass Storage

The various types of data storage devices available for each display generator are listed in the comparison tables. Most products offer various sizes of hard disks, streaming tape cartridges, floppy diskettes, or magnetic tapes.

System Resolution

In a raster graphics system, the term *resolution* has two separate meanings. The *system* resolution refers to the number of coordinate locations, or pixels, that can be stored in the display memory. The *display* resolution is the fixed number of pixels viewable on the screen of the monitor. Therefore, a monitor with a 512-by-512 display resolution would contain a total of 262 144 pixels on its display surface. A 512-by-512 pixel array would be considered medium resolution; a 1024-by-1024 array would be classified as high resolution (ref. 1).

The system resolution may be much larger than the display resolution; however, the total amount of data sent to the monitor for each refresh cycle must be equal to or less than the monitor resolution. For example, a monitor containing a 1024-by-1024 resolution may display a 1024-by-1024 or 512-by-512 image but not a 2048-by-2048 image. Some display generators have the capability to program the system resolution, thus providing the ability to drive monitors of various display resolutions.

Refresh Rate

The refresh rate is the number of times per second that the display raster is redrawn on a raster-scan monitor. This value is expressed in hertz (Hz), or cycles/second. With a raster monitor, an electron beam traces a fixed pattern of parallel lines across the phosphor-coated screen from left to right, top to bottom (see fig. 5). In one complete refresh cycle, every pixel in each scan line on the screen is "drawn" giving the ability to display solid or continuously shaded objects. Since the light emitted by the phosphors on the screen decays rapidly, the rate at which the raster is drawn should be fast enough to produce a flicker-free image (ref. 2). This rate varies depending on the intensity of the light source (a higher intensity causes a higher flicker-rate threshold) and the type of scanning used (interlaced or noninterlaced). With interlaced scanning, one entire frame is drawn by interleaving two fields. The first field displays all odd-numbered scan lines, while the second field displays all even-numbered scan lines. Therefore, in a display that is 30 Hz interlaced, each field is drawn in 1/60 of a second. This aids in reducing the large-area flicker that is present at a 30-Hz noninterlaced refresh rate since adjacent scan lines are updated every 1/60 of a second (ref. 1).

As with the resolution, some graphics systems offer a programmable refresh rate.

CRT Display Technology

The resolution and diagonal dimension of each CRT screen is listed. Some systems include a third party monitor; others do not provide any type of CRT.

Hardware Assist Features

The overall speed of a display generator can be enhanced by performing certain functions in hardware. Some of these include coordinate transformations, color fill, hidden line removal, clipping, polygon fill, and symbol generation. A very large-scale integration (VLSI) graphics engine which utilizes parallel pipelining also increases overall system performance. Graphics systems having real-time capability generally contain several, if not all, of these hardware assist features.

Maximum Number of Bit Planes

The display memory of a graphics system can be organized into multiple planes. In a bit-mapped system, the bits describing a pixel are accessed in parallel, with one bit being taken from each memory plane. One use of multiple memory planes is to create various hues on a color monitor or shades of gray on a black and white monitor. For example, a system with 24 planes allocated for a pixel word, 8 planes assigned to each primary color (red, green, and blue), as shown in figure 6, can produce approximately 16.7 million colors (2^{24}) (ref. 1).

Multiple planes can also serve other purposes. Each memory plane can hold an entirely different black and white image. Therefore, the static portions of a dynamic display which are to remain unaltered can be written into several planes while those portions which are continually changing are written to other planes. This will save in the overall update cycle time since the static portions of the display are drawn only once. The number of planes that should be reserved for the static areas of the image is determined by the number of colors to be used in these areas. For example, a system containing eight bit planes has 256 (2^8) colors available. If the static areas use eight colors, three bit planes are needed for these areas ($x = \ln 8/\ln 2 = 3$, where x is the number of bit planes needed), leaving five bit planes for the dynamic portions of the display (ref. 1).

Number of Color Display Ports

The number of color output ports emerging from a graphics system determines the number of monitors that can be driven simultaneously with unique display information (the number of different displays that can run independently).

Maximum Simultaneous Colors

As stated above, the number of colors available is 2^n, where n is the number of bit planes designated to describe a pixel. Some systems can display all these colors on the screen at one time, while others can display only a subset. The number of colors displayable simultaneously depends on the configuration of the hardware.

Interactive Devices

There are many different methods of interacting with a display generator. The following list of interactive devices was included in the survey: mouse, trackball, joystick, touch overlay, digitizing tablet, voice, and keyboard, many of which are illustrated in figure 7.

Operating System

An operating system is the software that manages all components of a computer. It schedules the computer's resources so the user programs run in an efficient manner. Most of the surveyed graphics systems either use some form of the Unix operating system, developed at Bell Laboratories, or the Virtual Memory System (VMS) operating system for Digital Equipment Corporation (DEC) equipment.

High-Level Language

A high-level programming language is a method of controlling a computer. It is composed of a sequence of instructions that specify operations to be performed by the CPU. Some high-level languages are rather sentencelike in structure and require little knowledge of the internal hardware of the computer. Programs written in high-level languages are also more portable, often requiring only minor changes to run on various machines. FORTRAN, Pascal, C, and Basic are examples of high-level languages.

For a graphics computer, a high-level language generally provides a means of calling graphic subroutines that, when executed, produce a display on the CRT screen. Although a high-level language is usually simpler to utilize, a lower level programming language is most often faster during the execution phase.

Graphics Standards

Graphics standards provide the interface between application software and the associated graphics engine (ref. 5). These standards have been designed in a device-independent manner to allow software portability between various graphics systems.

Graphics standards have been evolving over the past decade. Currently there are five in existence: Graphical Kernel System (GKS), GKS-3D, Programmer's Hierarchical Interactive Graphics System (PHIGS), Computer Graphics Interface (CGI), and Computer Graphics Metafile (CGM). The Core System, although not considered a formal standard, serves as the basis for packages provided by many vendors. Most of these standards are still in the draft stage. Formal approval of standards are made through the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO) (ref. 6).

A majority of the surveyed systems conform to one or more of the standards. Only those standards encountered in the survey are discussed.

Core System. The Core System was the first proposed graphics software standard and has served as a basis for the present formal standards (ref. 6). It was developed by the Graphic Standards Planning Committee of the Special Interest Group on Computer Graphics of the Association for Computing Machinery (ACM SIGGRAPH GSPC) in 1977 and was revised in 1979 (ref. 7). Core supports three-dimensional functions as well as two-dimensional, and there are many implementations in existence (ref. 8). It is oriented toward line-drawing functions (ref. 9) and is most suitable for use on stroke systems (ref. 1).

Graphical Kernel System (GKS). GKS was published as International Standard (IS) 7942 in August 1985 and as ANSI X3.124 in October 1985 (ref. 6). This raster-oriented standard was heavily influenced by the Core System but is much more restricted in structure (ref. 8). GKS is limited to two dimensions; however, a three-dimensional version (GKS-3D) is in the review stage and is expected to be formally approved some time in 1987 (ref. 10).

Programmer's Hierarchical Interactive Graphics System (PHIGS). PHIGS is a proposed two- and three-dimensional standard that was modeled after GKS. It is a hardware-independent application interface for graphics output and interactive input (ref. 9). This standard is presently in the draft stage (ref. 6).

Computer Graphics Interface (CGI). CGI is a two-dimensional hardware-independent standard that serves as an interface between a graphics package and the device driver for controlling an input or output device. This standard is closely related to both GKS and PHIGS (ref. 9). Throughout its development, CGI has had several name changes (Virtual Device Interface (VDI) as well as Computer Graphics Virtual Device Interface (CG-VDI, ref. 11). This standard is presently in the draft stage and is available for public review during early 1987 (ref. 6).

General Information

Three-dimensional (3D) capability. In a 3D system, graphic objects are defined in terms of

x, y, and z coordinates, thus giving the objects depth as well as width and height. Since display devices are two-dimensional (2D), the 3D objects must be projected onto a 2D projection plane before being drawn. With this technique, the displayed image appears to have depth although it is actually drawn in two dimensions.

Stereo three-dimensional capability. With stereo 3D, independent "left-eye" and "right-eye" views of a display are created at high speed by the graphics system to utilize the human perception characteristic of stereopsis to provide unique depth cues. Special viewing hardware and programming techniques are necessary to achieve this effect. A system that provides stereo 3D capability also has 3D capability, but the converse is not necessarily true.

NTSC capability. NTSC (National Television System Committee) scan standard is a color-encoding technique adopted in 1953. This standard was the first public broadcasting color signal with monochrome compatibility (ref. 1). Many raster systems have a NTSC output signal option which gives the system video recording capability as well as the ability to drive a standard television set (ref. 2).

Video digitizer. An input video digitizer is a hardware board which is inserted into a slot in the graphics system. The digitizer accepts data from a video source and stores it in the display memory. This digitized data is then in a form identical to data produced from a graphics program and can be manipulated accordingly.

Video disk interface. A graphics display generator containing a video disk interface allows direct control of a video disk player through built-in command sequences. This interface could permit the overlay of graphics images onto the video image, giving the capability to produce a variety of effects.

Real-time dynamic animation. Real-time dynamic animation is the ability of a graphics system to update and display graphic images very rapidly from user inputs to the system or from computations within the main processing unit. This capability is a necessity for performing aircraft simulation or any other applications requiring data inputs through a man-machine interface.

Numerical data are not given for vector drawing and shading rates since there is no set standard for arriving at these figures. One vendor may use 1-inch clipped and transformed vectors to arrive at a drawing rate, while another vendor might use 6-inch unmanipulated vectors.

ICON/FONT editor. An ICON is a symbol representing a function to be performed by the processor. Selecting an ICON replaces the task of typing in an alphabetic command. A FONT describes the size and style of the alphanumeric characters to be drawn to the screen. An ICON/FONT editor permits the programmer to modify existing ICON/FONTs or create new ones from scratch.

Windowing. Many display generators on the market today offer some form of windowing. This windowing capability allows a user to view multiple processes simultaneously on one monitor. Certain constraints were placed on the windowing ability reviewed in this survey to meet criteria set for aircraft system and subsystem displays. Only nonoverlapping windows with dynamic displays running in each simultaneously were considered. Figure 8 shows an example of nonoverlapping windows for an aircraft system and subsystem display. Also, while a user is interacting with one window, the others must be continually updating from the processor. Some systems permit updates only of the window in which the user is currently working.

Raster System Classification

Raster graphics systems may be categorized by several methods. For example, these systems could be classified according to their speed (real-time vs. non-real-time) or by their drawing dimensionality (2D vs. 3D). In this report, raster display generators are grouped according to their main processing dependency, for example, workstation or terminal.

Workstations

A workstation is a stand-alone unit containing a CPU as well as a DPU. It is a totally self-sufficient system that does not depend on a host computer for its processing power, although most workstations can interface to a host through some type of networking. The surveyed systems that would be classified as strictly workstations are given in table II. The appendix contains the vendor addresses from which product literature and survey responses were received. (Several graphics systems can incorporate third party products to meet some of the surveyed characteristics. For the purposes of this paper, only those features offered by the manufacturing vendor are considered.)

Adage 6500 series. The Adage, Inc., 6500 series of workstations contain a System Unit that houses a DEC MicroVAX II microcomputer and a proprietary OCEAN graphics engine. These are real-time systems with stereo 3D capability. They have a 1024-by-1024 system resolution and operate at 60 Hz noninterlaced. The CPU type and word length is that of the DEC MicroVAX II.

Apollo model DN580 Turbo. The Apollo Computer, Inc., model DN580 Turbo is a real-time workstation that operates in a 2048-by-1024 60 Hz noninterlaced mode with 1280-by-1024 viewable and incorporates most of the hardware assist features listed.

Hewlett-Packard model 98700H. The Hewlett-Packard 98700H display generator must have as its host the Series 500 model 550 computer from the HP 9000 family. The Model 550 computer can communicate to any standard ASCII host. This computer can support one to three HP 98700H display generators and up to 32 standard terminals. The HP 98700H is a real-time system with stereo 3D capability. It has a 1024-by-1024 system resolution with 1024-by-768 viewable and operates at 60 Hz noninterlaced. This display generator also offers most of the hardware assist features included in the survey.

Jupiter J-Station. The Jupiter Systems, Inc., J-Station is a raster display generator that interfaces to the DEC MicroVAX I or MicroVAX II. The graphics system is packaged in a DEC Tower that matches the appearance of the DEC MicroVAX cabinet. The DEC MicroVAX must be purchased separately however. This workstation offers a programmable system resolution and refresh rate. Its four color display ports are capable of operating at different resolutions simultaneously. The CPU type and word length for this workstation is also that of the DEC MicroVAX.

Silicon Graphics IRIS 3000 series. The Silicon Graphics, Inc., IRIS 3000 series of workstations are real-time systems having stereo 3D capability. They contain all the hardware assist features mentioned as well as a NTSC output option. These systems have a resolution of 1024-by-1024, with only 1024-by-768 viewable, and can operate at 60 Hz noninterlaced or 30 Hz interlaced.

SUN model 3/260C. The Sun Microsystems, Inc., model 3/260C is a self-contained unit that operates in a 1152-by-900 66 Hz noninterlaced mode. This real-time display generator utilizes all the hardware assist features surveyed.

Comparison summary. All the workstations surveyed, except for Jupiter's, are well suited for real-time applications. While the Jupiter workstation does not provide real-time capability, it is very flexible when it comes to configuring its output signal attributes, having a programmable resolution and refresh rate and four color display ports. The Adage, Apollo, Hewlett-Packard, and Sun systems currently offer only 256 simultaneous colors, which may be too few if intense shading is necessary. Both the Jupiter and the Silicon Graphics workstations allow 16.7 million colors simultaneously; however, no shading software is available through Jupiter. All surveyed systems offer basically the same resolution and refresh rates, except for the Sun system, which is uncommon with a 1152-by-900 resolution and 66-Hz noninterlaced refreshed rate.

Terminals

A raster graphics system would be classified as a terminal if it must be interfaced to a host computer. This host can usually be one of several products. Most terminal systems offer a direct memory access (DMA) interface to the host computer, providing extremely high-speed memory access. A DMA interface would be desirable for real-time applications, such as aircraft simulations. Those display generators surveyed that would be considered terminal systems are listed in table III. The CPU type and word length for these systems depends on the host processor.

The Adage model 3000. The Adage, Inc., model 3000 real-time terminal system interfaces to Prime, Gould Sel, and most DEC computers. The comparison table lists several interactive devices that can be used directly with the Adage 3000 terminal. This is possible only if the display generator contains a peripheral microprocessor. There are two unique high-level languages (ICROSS-3000 and FSS) associated with the Adage 3000 terminal. ICROSS-3000 is a C-like language presently under development. FSS is a package of graphics FORTRAN Support Subroutines that are callable from a FORTRAN program. This system also offers stereo 3D capability, two color output ports, a NTSC output, an input video digitizer, and programmable resolution and refresh rates. The mass storage unit and operating system are host dependent.

New GEA model NWX 340. The New GEA Corp. model NWX 340 is a real-time system that requires a DEC, Hewlett-Packard, IBM, Prime, or Harris computer as a host. It operates at either 2048-by-1024 or 4096-by-2048 system resolution with 1280-by-1024 viewable and 60-Hz noninterlaced refresh rate. This display generator contains two color output ports and an input video digitizer option.

Raster Technologies model One/380. The Raster Technologies, Inc., model one/380 interfaces to computers manufactured by DEC, Gould, Prime, Data

General, Ridge, Celerity, Sequent, IBM, and others. This system offers stereo 3D capability, one to five color display ports, and an NTSC output option. It has a 2560-by-2048 system resolution with 1280-by-1024 viewable and can operate at either 60-Hz noninterlaced or 30-Hz interlaced refresh rate. There is no high-level language associated with this product. It is programmed only through FORTRAN callable graphics primitives. As with the Adage 3000 system, the mass storage devices and operating system are host dependent.

Comparison summary. The Adage and New GEA systems provide real-time capability where the Raster Technologies engine is geared more towards three-dimensional computer-aided design/computer-aided engineering applications. All three terminal systems provide 16.7 million simultaneous colors and more than one color display port. The Adage system can produce an image for a wide variety of display media since it has a programmable resolution and refresh rate; however, the New GEA machine offers a choice of two resolutions, while the Raster Technologies engine offers two refresh rates.

Concluding Remarks

High-resolution raster graphics engines have the potential for widespread use in crew workstations of the future. These display generators can produce realistic synthetic visual scenes with their shading and three-dimensional capabilities. Although certain undesirable effects, such as aliasing and large-area flicker, can be present, the rapidly advancing microcircuit and microprocessor technology and increasing resolutions should help minimize these considerably.

The data presented from the survey give information on various characteristics of high-resolution, high-performance raster graphics engines. Choosing between a workstation and a terminal, between three-dimensional and stereo three-dimensional capability, or even between real-time and non-real-time capability depends on the application for which the graphics engine will be used.

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Appendix
Vendor Addresses

Adage, Inc.
One Fortune Dr.
Billerica, MA 01821
(617) 667-7070

Apollo Computer, Inc.
330 Billerica Rd.
Chelmsford, MA 01824
(617) 256-6600

Hewlett-Packard Company
3200 Hillview Ave.
Palo Alto, CA 94304
(415) 857-3456

Jupiter Systems, Inc.
1100 Marine Village Pkwy.
Alameda, CA 95401
(415) 523-9000

New GEA Corporation
335 Oser Ave.
Hauppauge, NY 11788
(516) 434-8400

Raster Technologies, Inc.
9 Executive Park Dr.
N. Billerica, MA 01862
(617) 692-7900

Silicon Graphics, Inc.
2011 Stierlin Rd.
Mountain View, CA 94043
(415) 960-1980

Sun Microsystems, Inc.
2550 Garcia Ave.
Mountain View, CA 94043
(415) 960-1300

Table I. Abbreviations Used in Comparison Tables

Codes for hardware (HW) assist features:

CT	coordinate transformation
P	parallel pipelining
VG	VLSI graphics engine
CF	color fill
HLR	hidden line removal
CL	clipping
PF	polygon fill
SG	symbol generator

Codes for interactive devices:

M	mouse
T	trackball
J	joystick
TO	touch overlay
D	digitizing tablet
V	voice
K	keyboard

Codes for general information:

3D	3D only
S3D	stereo 3D capability
NTSC	NTSC capability
VDIG	video digitizer
VDI	video disk interface
RT	real-time dynamic animation
IFE	ICON/FONT editor
W[N]	windowing conforming to constraints given, where N is the number of windows possible

Miscellaneous codes:

Hz	Hertz (cycles/second)
NI	noninterlaced
I	interlaced
FOR	FORTRAN
MB	megabytes
M	million
K	thousand

Table II. Workstation Comparison Chart

Characteristics	Vendors		
	Adage	Apollo	Hewlett-Packard
Model	6500 series	DN580 Turbo	550 & 98700H
Cost	$42K	$58K	$25K & $15K
Processor type	DPU: AMD29116	CPU: MC68020 DPU: Custom	CPU: Proprietary DPU: Proprietary
Word length	DPU: 32 bit	CPU: 32 bit DPU: 16 bit	CPU: 32 bit DPU: 32 bit
Display memory	Up to 4 MB	2 MB	Up to 10 MB
Storage	Two 5-in. floppy disks, 2 hard disks, 600-MB streamer	Hard disks, 86 to 190 MB, 60-MB tape cartridge	Floppy disks, hard disks, streamers, magnetic tapes
System resolution	1024 × 1024	2048 × 1024 1280 × 1024 viewable	1024 × 1024 1024 × 768 viewable
Refresh rate	60 Hz NI	60 Hz NI	60 Hz NI
CRT display technology	1024 × 1024 19 in.	1280 × 1024 19 in.	Trinitron: 19 in. 1024 × 768
HW assist features	CT, P, CL, SG	CT, P, VG, CF, HLR, CL, PF	CT, P, VG, CF, HLR, CL, PF
Max. no. bit planes	8	8	8
No. color ports	1	1	1
Max. no. simultaneous colors	256	256	256
Interactive devices	M, D, K	M, T, K	M, D, K, 12-in., TO
Operating system	MicroVMS	Unix, AEGIS	Unix
High-level language	FORTRAN, Pascal, C, LISP, Ada	FORTRAN, C, Pascal, LISP	FORTRAN, C, Pascal
Graphic standard	GKS, Core	PHIGS & Core	CGI
General information	S3D, RT	3D, RT, IFE, W[24]	S3D, RT, IFE, W[Infinite]

Table II. Concluded

Characteristics	Vendors		
	Jupiter	Silicon Graphics	Sun
Model	J-Station	IRIS 3000 series	3/260C
Cost	$20K	$40K	$45K
Processor type	DPU: AMD2901	CPU: MC68020 DPU: Custom	CPU: MC68020 DPU: AMD29116
Word length	DPU: 16 bit	CPU: 32 bit DPU: 32 bit	CPU: 32 bit DPU: 16 bit
Display memory	0.5 to 9 MB	8 to 16 MB	1 to 3 MB
Storage	31- or 70-MB hard disks, 95-MB streamer	20-MB, 72-MB, & 170-MB hard disks	280-MB hard disks, 60-MB streamer, 150-MB tape drive
System resolution	Programmable up to 1280 × 1024	1024 × 1024 1024 × 768 viewable	1152 × 900
Refresh rate	60 Hz NI programmable	60 Hz NI, 30 Hz I	66 Hz NI
CRT display technology	1280 × 1024 19 in.	1024 × 768 19 in.	1152 × 900 19 in.
HW assist features	CT, VG, CF, CL, PF	CT, P, VG, CF, HLR, CL, PF, SG	CT, P, VG, CF, HLR, CL, PF, SG
Max. no. bit planes	28	32	8
No. color ports	4	1	1
Max. no. simultaneous colors	16.7M	16.7M	256
Interactive devices	M, J, D	M, D, K	M, K
Operating system	MicroVMS, Ultrix	Unix	Unix
High-level language	FORTRAN, C, Pascal	FORTRAN, C, Pascal, LISP	FORTRAN, C, Pascal, LISP
Graphic standard	Core	None	Core, GKS, CGI
General information	S3D, NTSC, IFE	S3D, NTSC, RT, W[64]	3D, RT, IFE, W[Infinite]

Table III. Terminal Comparison Chart

Characteristics	Vendors		
	Adage	New GEA Corp.	Raster Technologies
Model	3000	NWX 340	One/380
Cost	$50K	$35K	$31K
Processor type	DPU: AMD2903	DPU: AMD29116	DPU: AMD2901
Word length	DPU: 32 bit	DPU: 32 bit	DPU: 16 bit
Display memory	Up to 12 MB	2 MB	1 to 16 MB
Storage	Host dependent	1183-KB floppy disks, hard disks, up to 500 MB	Host dependent
System resolution	Programmable up to 2048 × 4096 1024 × 1024 viewable	2048 × 1024 4096 × 2048 1280 × 1024 viewable	2560 × 2048 1280 × 1024 viewable
Refresh rate	60 Hz NI, 30 Hz I programmable	60 Hz NI	60 Hz NI, 30 Hz I
CRT display technology	None	1280 × 1024 19 in.	Sony: 19 in. 1280 × 1024
HW assist features	CT, P, CF, SG	CT, P, CF, HLR, CL, PF, SG, VG	CT, VG, CF, HLR, CL, PF, SG
Max. no. bit planes	32	32	64
No. color ports	2	2	1 to 5
Max. no. simultaneous colors	16.7M	16.7M	16.7M
Interactive devices	T, J, D, K	M, T, J, TO, D, K	M, T, TO, D, K
Operating system	Host dependent	VMS, MVS, Unix	Host dependent
High-level language	ICROSS, FSS	FORTRAN, C	None
Graphic standard	None	Core, GKS	None
General information	S3D, NTSC, VDIG, RT, W[5]	3D, VDIG, RT, W[16]	S3D, NTSC

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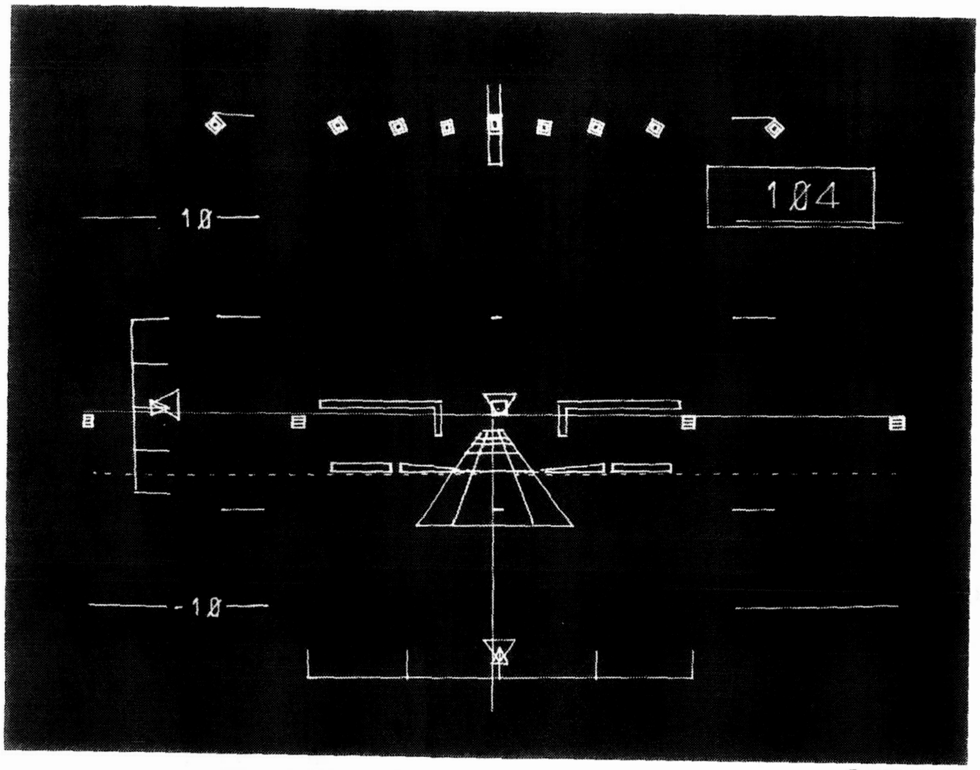

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Figure 1. Stroke-generated primary flight display.

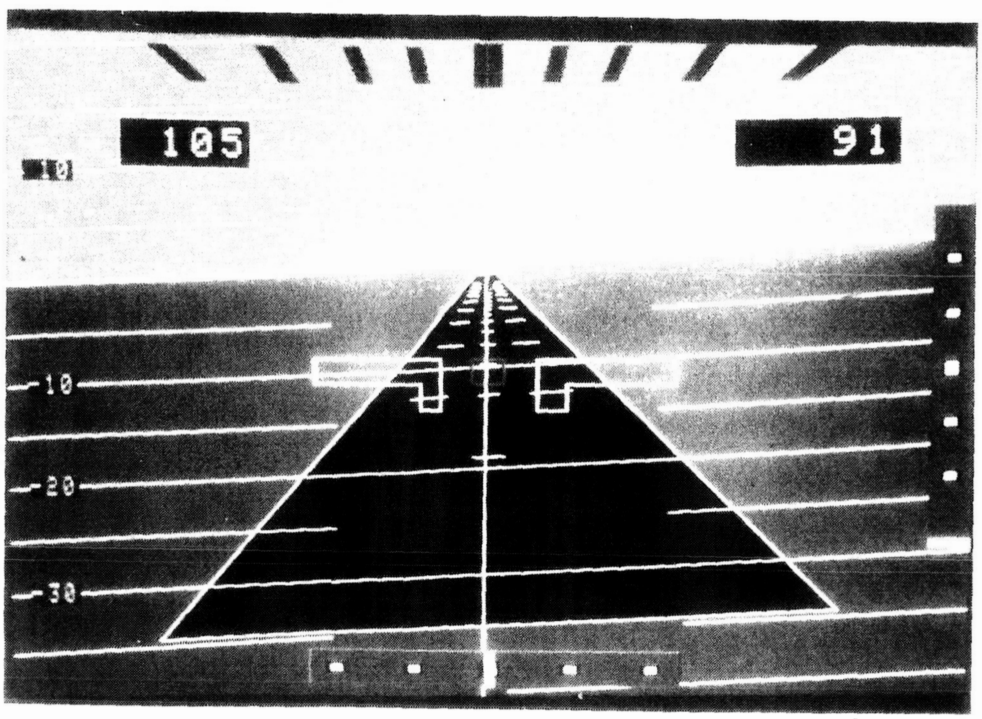

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Figure 2. Raster-generated primary flight display.

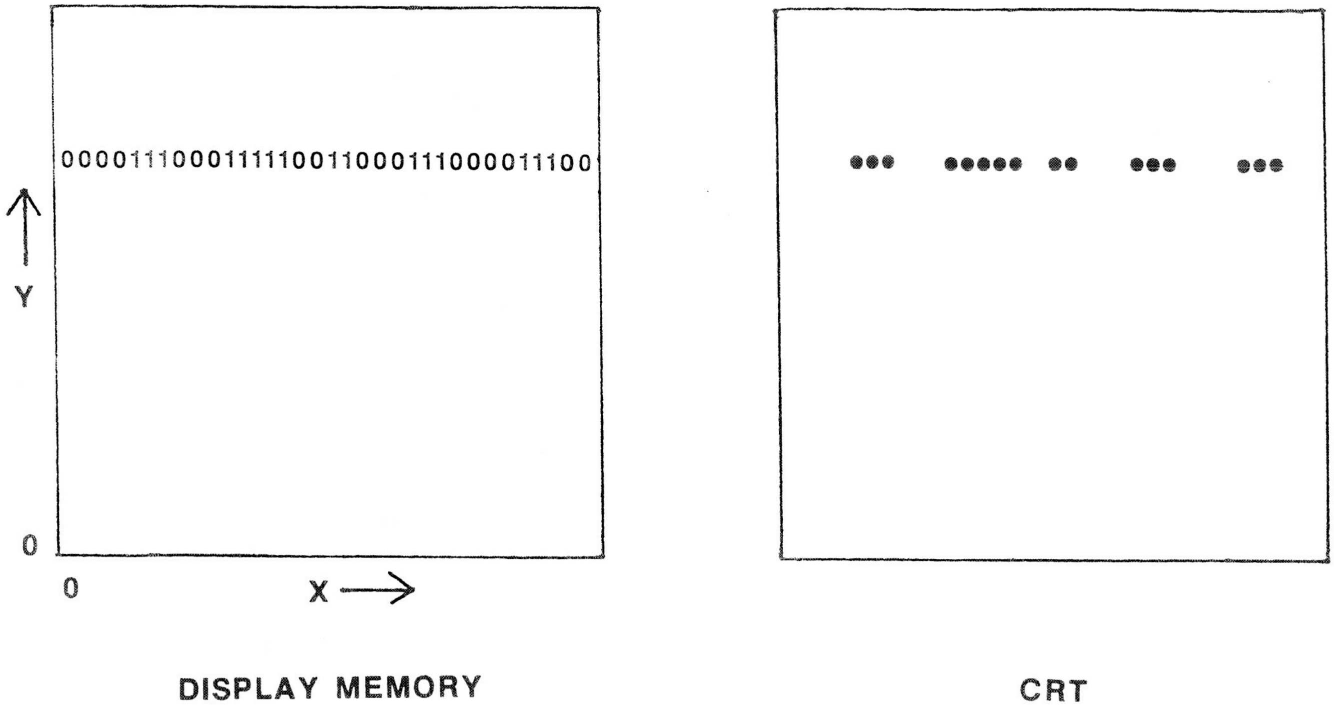

Figure 3. One-to-one relationship between display memory and CRT.

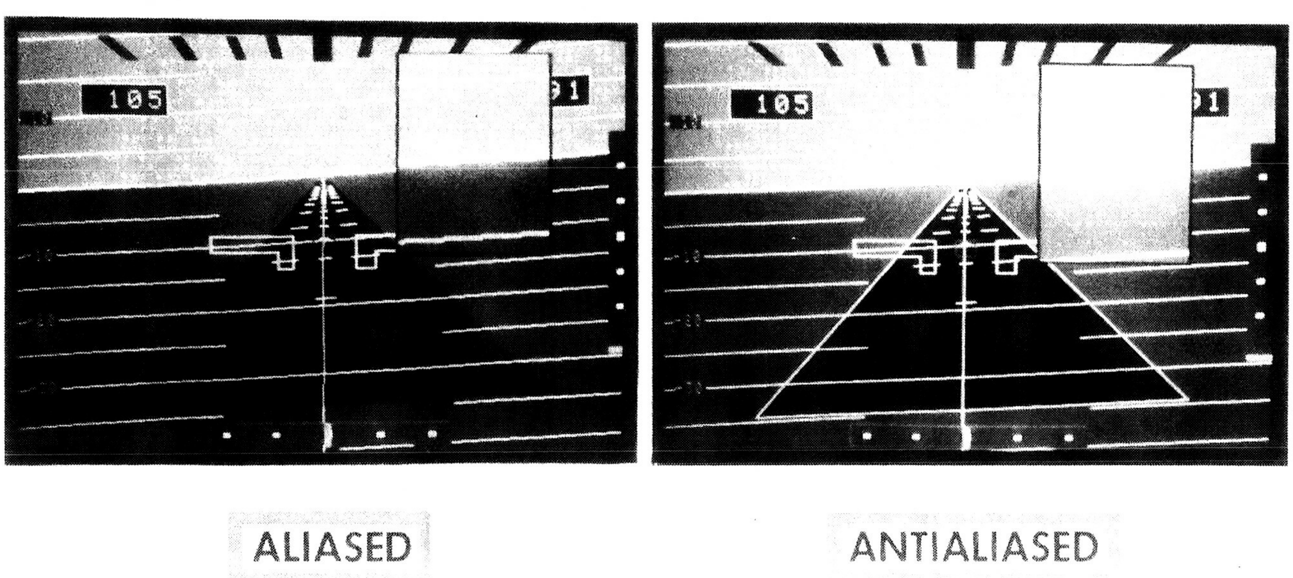

Figure 4. Aliased vs. antialiased symbology in a primary flight display.

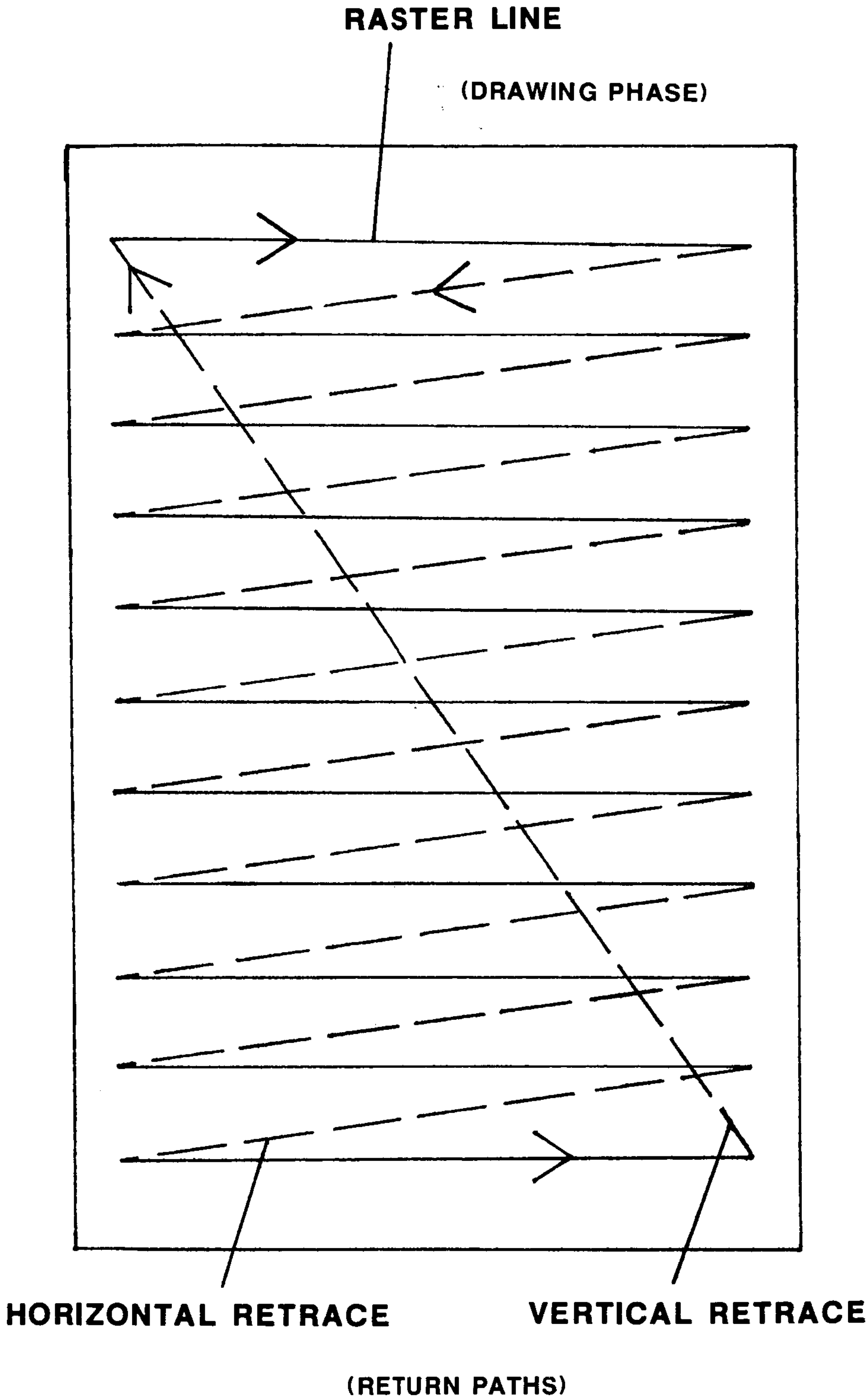

Figure 5. Raster scan pattern.

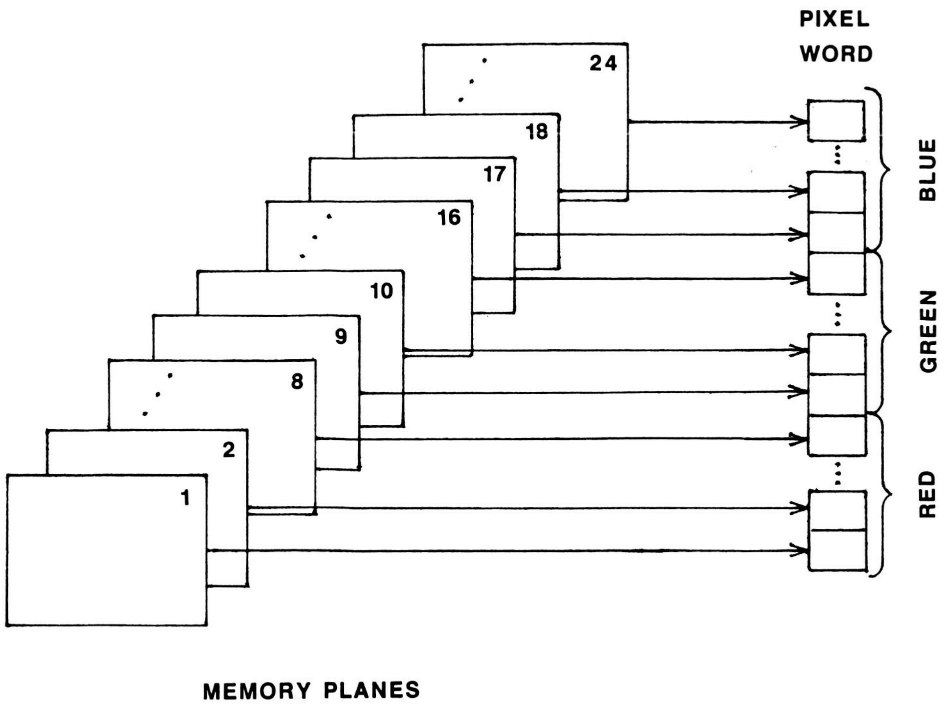

Figure 6. Memory plane utilization for pixel color determination.

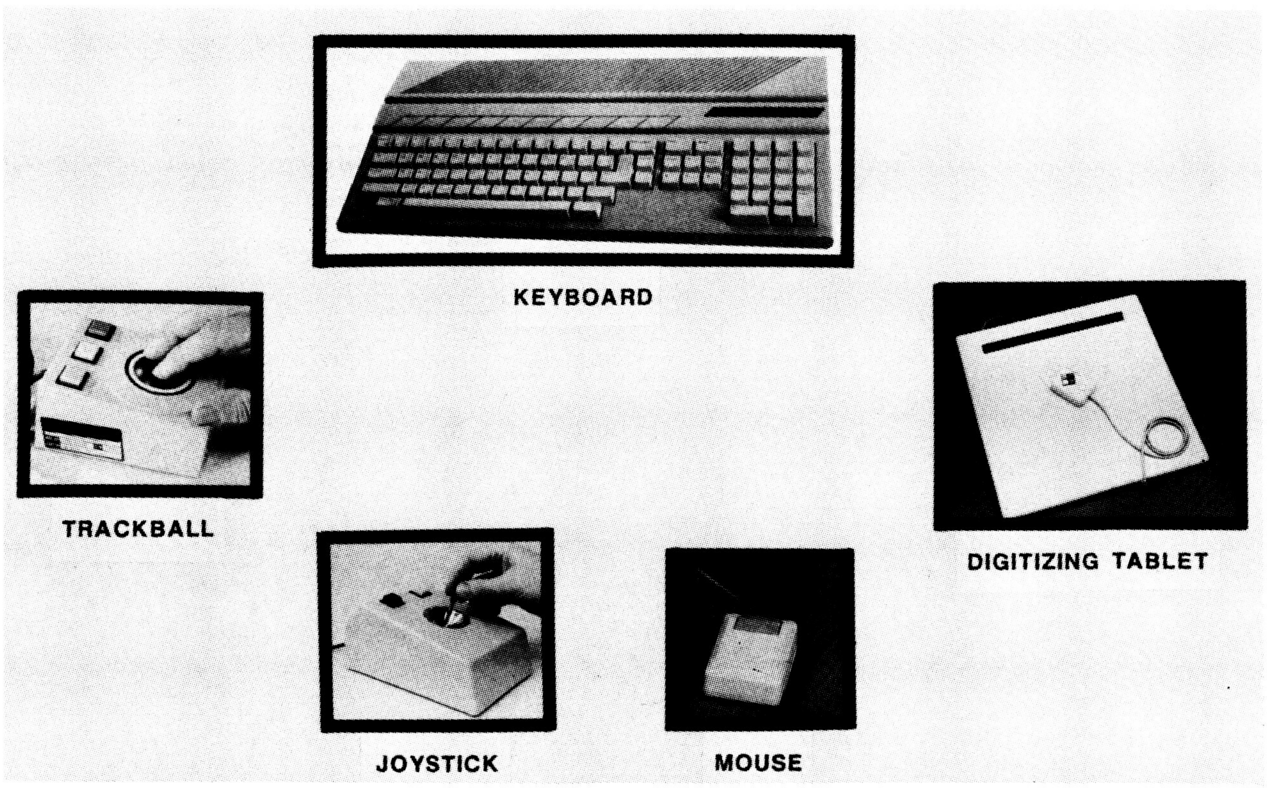

Figure 7. Interactive input devices.

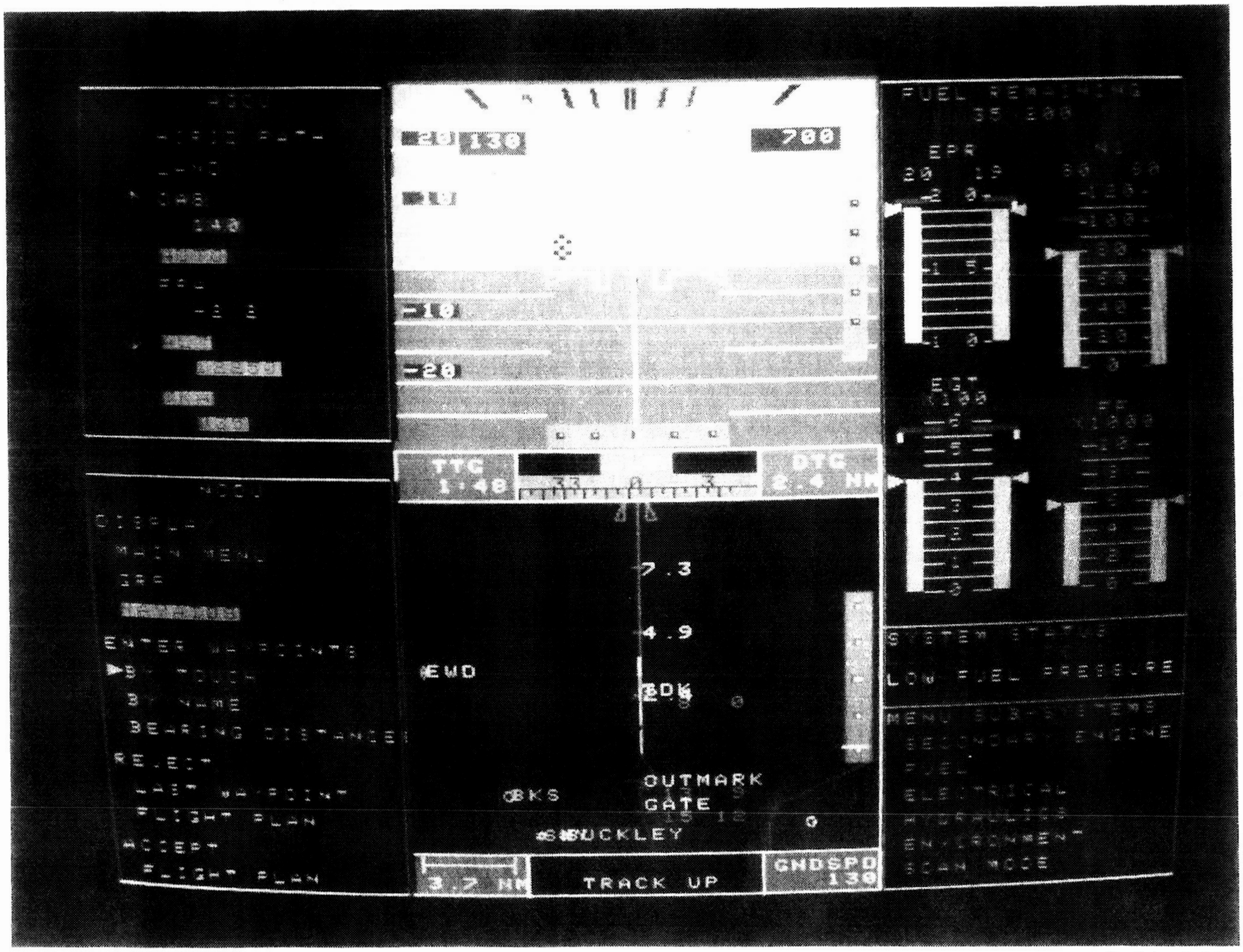

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Figure 8. Nonoverlapping multiple windows.

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15. Supplementary Notes

16. Abstract

This paper presents data obtained on high-resolution raster graphics engines that are currently available on the market. The data were obtained through survey responses received from various vendors and also from product literature. The questionnaire developed for this survey was basically a list of characteristics desired in a high-performance color raster graphics system which could perform real-time aircraft simulations. Several vendors responded to the survey, with most reporting on their most advanced high-performance, high-resolution raster graphics engine.

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