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THE RAND VIDEO GRAPHIC SYSTEM — AN APPROACH TO A GENERAL USER-COMPUTER GRAPHIC COMMUNICATION SYSTEM

K. W. Uncapher

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10. ABSTRACT

A report prepared for the AGARD Avionics Panel Technical Symposium on Data Handling Devices, Istanbul, Turkey, 1-4 June 1970. Cathode-ray-tube graphic displays offer one of the most powerful and useful man-machine communication paths. The Rand Video Graphic System offers one implementation. It serves 32 consoles; each has a full range of interaction and full graphics, and accommodates up to 8 different input devices. Each console serves as the general graphic terminal for all the user's computer-based needs. The user can access several computers from any terminal. The system is based on the use of 873-line TV monitor in each terminal. Scan conversion and buffered storage are centralized to improve performance and reduce cost. The report describes system components, operating environment, hardware and software, consoles, and reliability and performance. An all-digital approach to the video system is now being designed at Rand.

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PREFACE

This report was prepared for the *XXth AGARD* Avionics Panel Technical Symposium on Data Handling Devices* held in Istanbul, Turkey, June 1-4, 1970. The focus is on general system information that is important to the user. Technical detail and technical jargon have been avoided to assist the noncomputer specialist in understanding the significant advantages of the video approach to computer graphics.

T. O. Ellis of Rand is responsible for a major part of the total system design. The Image Distribution System portion of the system was acquired under a subcontract with IBM, Los Gatos. Harold Martin was project engineer on the IDS.

*Advisory Group for Aerospace Research and Development.

CONTENTS

INTRODUCTION

Cathode Ray Tube (CRT) graphic displays offer one of the most promising communication paths between man and the computer. The significant advantages of displaying alphanumeric information on graphic consoles include the speed at which several hundred characters can be displayed, great flexibility and lack of noise in presenting data, and fast and quiet erasure. For more esoteric problems, where dynamic recognition of events is not otherwise discernible, graphic display offers the greatest hope for new levels of problem-exploration and problem-solving capability. That is, via graphic display techniques, the user often can view a scene, structure, or relationship on a display in such a way as to gain new insight about his problem.

Thus, it appears as if one of the most powerful and useful man-machine communication paths is via a CRT display suitably augmented with flexible input device capability. The challenge is how to supply graphic terminals at sufficiently low cost to a community of concurrent on-line users and in such a form that the user's terminal is "personal" and that the terminal is the general communication instrument between the user and most of his computer needs. The Rand Video Graphic System (VGS) is an experiment directed at one implementation of these aspirations. This Report describes the operational philosophy, design, implementation, and operating experience of a general-purpose existing graphic system that is capable of:

1. Serving 32 consoles;
2. Permitting each console a full range of interaction from static displays to dynamic interaction with full graphic capability and with significant gray scale capability;
3. Permitting each user to communicate upon request with one of several computers and one of several services that might be resident in each computer;
4. Permitting most users to have a personal terminal—that is, one low enough in cost to allow the user to treat his terminal as personal property;
5. Providing the user with access to film files, natural pictures via TV cameras with concurrent viewing of computer-generated pictures;
6. Providing the user with a choice of input devices ranging from keyboard to light pen and tablet.

THE OPERATING ENVIRONMENT

Within the Rand environment, general-purpose time-sharing in one computer is far too difficult to pursue, given the current status of software. We have, therefore, distributed languages and programming systems across several computers. Thus, the level of time-sharing software for one computer is not exotic but is practical and flexible in accommodating the ever-changing problem mix and increasing demands for higher levels of interaction with graphic terminals on the part of users.

The VGS design philosophy is biased toward serving highly interactive users. It is this goal that has provided the greatest intellectual challenge, the greatest potential for system uniqueness, and the opportunity to service the broadest possible spectrum of interaction in a time-shared, multiuser, problem-solving environment.

The VGS design is based on use of television industry components as a means of significantly reducing system cost. More importantly, the use of television monitors as the display element in each console permits a full range of graphics (complex line drawings, vectors, gray scale, and display of over 4000 characters) at each terminal, and at an impressive cost reduction for the (local) graphic-station hardware [1-5].

THE VIDEO GRAPHIC SYSTEM DESCRIPTION

Figure 1 indicates the gross aspects of the system currently operating at Rand. The basic system concept is characterized by a central set of shared hardware connected to several computers and many terminals.

Any one of the service computers is callable from any console. Current service machines are the 360/40, 360/50, and 360/65. All are connected to an 1800 Communication Processor. The 1800 serves as a message switch and a communication coupler, allowing data, messages, and control sequences to be transmitted in either direction between consoles and the service machines.

Perhaps the most technically interesting portion of the system (Fig. 2) is the Image Distribution System (IDS) that lies between the 1800 and the consoles. The IDS consists of a microprogrammed graphic display control, a picture generator, three scan converters, a 32-channel central buffer store, a distribution panel, a graphic compare, and raster compare.

The microprogrammed graphic control's major functions are:

1. Control of scan converter and buffer track selection switches.
2. Decoding graphic orders for the picture generator.
3. Transference of data between the 1800 and the line and character

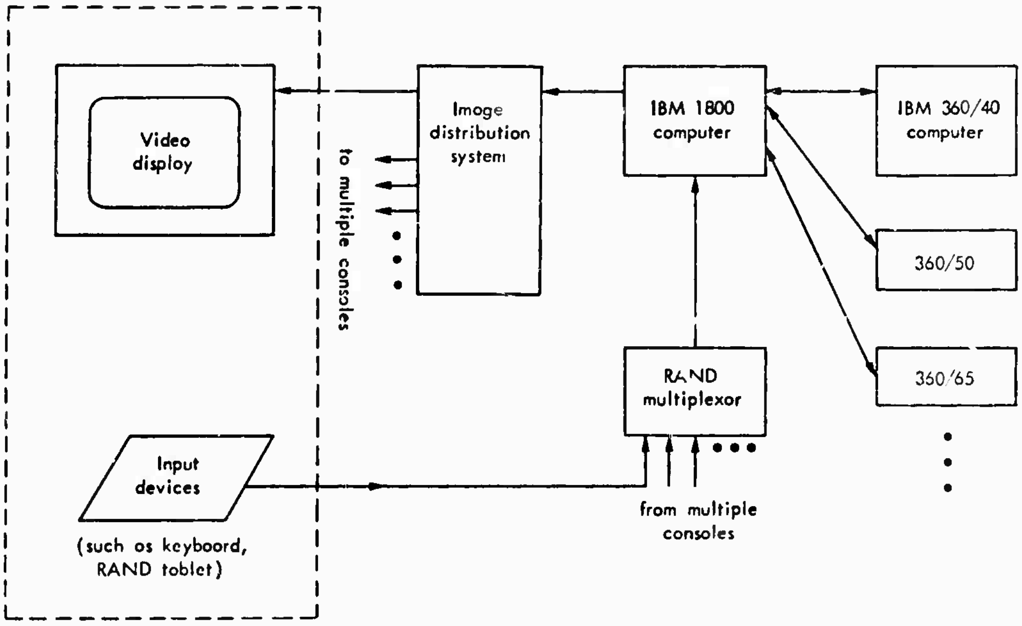

Fig. 1—Video Graphic hardware configuration

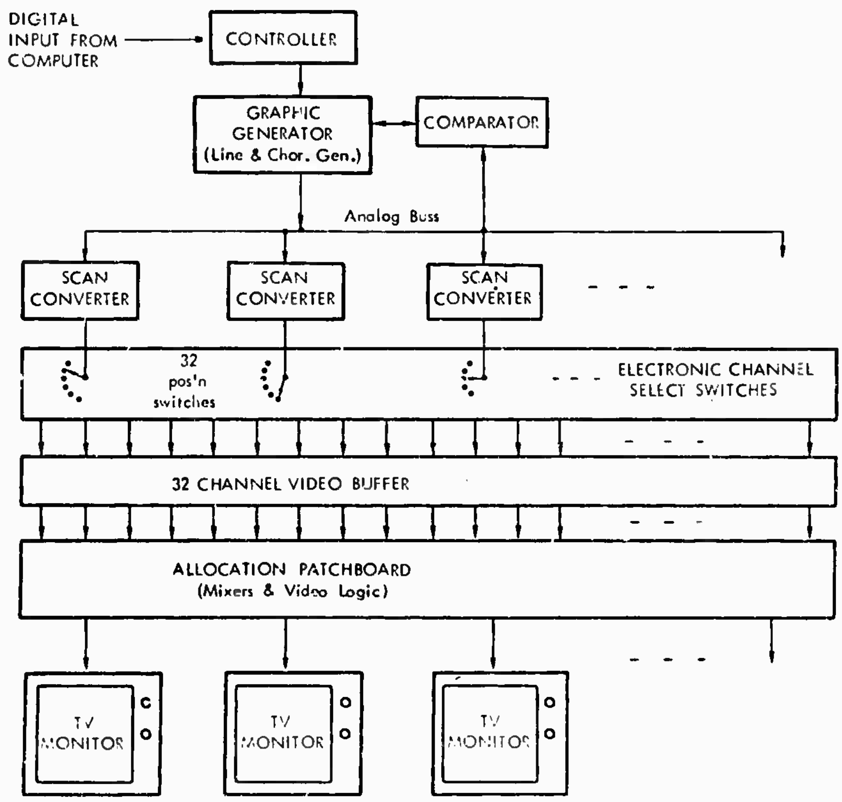

Fig. 2—Image Distribution System

generators in the picture generator.

4. Keeping the 1800 informed of the status of the scan converter and the picture generator.

For a given picture job, a block transfer of variable length is performed from the 1800 to the graphic control, with a header to select a scan converter and to select a buffer channel. Within the block, the header is followed by graphic orders and data that are interpreted and issued to the picture generator for line drawing, coordinate positioning, and character plotting.

The picture generator is a high-quality line and character generator. It converts the digital descriptions to x, y, and z (intensity control) analog vectors and positional information to be painted on the selected scan converter.

The scan converter translates the x, y, z signals to an electronic charge pattern on the target of a recording vidicon scan-conversion tube. A picture may be written ("painted") in any sequence desired. Once the charge pattern is painted on the target of the scan converter, the picture generator is available for generating another user's picture on another scan converter.

Once a picture is painted, the scan converter is switched to the raster scan mode and the stored image is scanned off (read) in an 873 line raster format with 2 to 1 interlace. The scanned signal is FM modulated, simultaneously stored on the selected video buffer channel (used for centralized refresh of the consoles), and displayed on the selected console. Before the paint cycle, any previous image on the target of the scan converter is erased in about 10 microseconds using a high-intensity strobe light to discharge the photoconductor target. Then the scan converter is ready for another paint cycle.

The common video buffer is a 32-track single read-write head per track disc. Each channel stores and refreshes one television picture. The recording per track is at a 10-megahertz analog video bandwidth. A programmable track-select switch routes an FM modulated video signal from the selected scan converter to the selected buffer track. The FM signal recorded on the disc is then demodulated and used to refresh the picture on the television monitor at 30 frames per second. All frame-rate signals are synchronized to the buffer.

Dynamic portions of a picture are updated by generation of a change in a service computer. Only the information that is changed is routed via the 1800 to update a track. Therefore, for text use only, one buffer channel per console is sufficient since a partial rewrite feature may be used to replace a single line of text. The partial rewrite feature allows rewriting any size horizontal band of the picture scan from one line to full screen. This band may be positioned at any vertical position desired. For full graphic dynamic pictures, two channels per console may be used, one for static portions and one for dynamic portions of the picture.

Signals from several buffer tracks can be summed linearly for transmission to the appropriate console. Noncoded information, such as natural pictures from a television camera, can be summed with coded pictures.

The distribution module is the output element of the Image Distribution System. Its functions are:

1. To connect consoles to the appropriate IDS channel.
2. To linearly mix, if desired, both signals from several buffer channels and noncoded, or recorded, information.

In certain types of graphic applications, it is desirable for the system hardware to be able to examine a picture to determine if any visible elements occur in a certain area of the display. This function is called graphic compare. It allows a program to detect the presence and identity of an image element within a variable program-defined rectangular "window" within the display area. The system can perform this test with or without concurrent track rewrite.

The raster compare function compares the video from one buffer channel with that from another to see if there are points on the picture where both have video information. This function was built in for experimental purposes only. For example, it will be used for complex scanning of natural pictures, wherein a computer-generated picture is compared with a natural image to derive coincidence information. The resultant information could be returned to the service machine for further control of the comparison picture.

Each terminal is connected via a pair of coax cables to an I/O multiplexor. One coax carries all signals (video, digital data, and audio) to the terminal, and another cable carries an identical format from the terminal to the central equipment, allowing full duplex communication with the terminals.

All station cables are terminated in an interface unit built by Rand that combines the signals on each outgoing coax and separates the signals incoming from the station. All of the incoming digital information is multiplexed into one of two 1800 read channels, depending on the data type. All outgoing data are demultiplexed from a single 1800 write channel.

Normal use of the Rand Tablet with any display system requires a plotted point in the display to continuously reflect the relative stylus position on the tablet. This function, called direct feedback, is performed in hardware in the Video Graphic System. The pen coordinates are equated to a time position in the television raster scan by synchronizing clock-driven counters to the rastersweep sync pulses. This produces a pulse in each field scan that is added to the video signal displayed by the station monitor.

THE CONSOLES

Each console is designed to be the personal property of each user. That is, each is low enough in cost to be a justifiable expense for a person with moderate to heavy use rates. Consoles are designed to operate in the user's most productive problem-solving environment—his office. Each console is connected to the distribution module via two coax cables up to 2500 feet long.

Figure 3 is a block diagram of the console. Each console modem allows the user a choice of up to eight input devices; thus, the user has input flexibility to match the output flexibility of graphically displayed information. Currently available input devices are a Selectric keyboard (standard on all consoles), a Rand Tablet, a Graf Pen tablet, a light pen, and a fan-out device that will accommodate up to 64 simple data entry keyboards per station. Each console has a full duplex audio that allows the user either to communicate to other machine operators or consoles, or to hear on his station audio portions of regular or closed circuit telecasts.

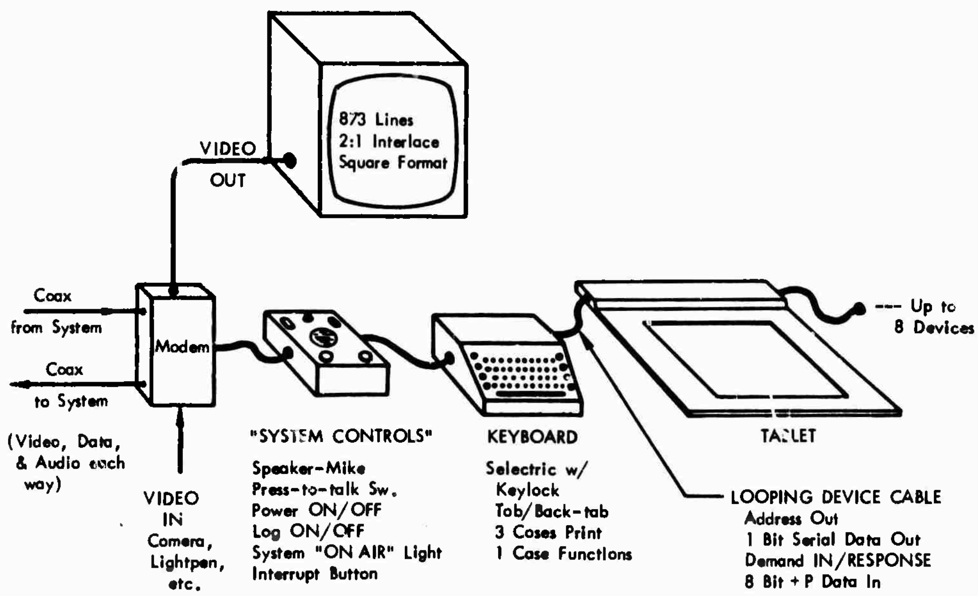

Fig. 3—Video Graphic station configuration

The keyboard has upper/lower case, a third case for special symbols, and a fourth case for user-described function keys. Each console has control buttons and lights to keep the user constantly informed of the following station conditions:

1. Station power switch and light;
2. System ready light;
3. Connect button (log on);
4. Station on-line light;
5. Disconnect button (log off).

Figures 4 and 5 show the console as used in two different applications. Each console can display 52 lines of characters with 74 characters per line, flicker-free and readable. Further, each station can handle full graphics and continuous gray scale. The television monitors are, of course, insensitive to the complexity of the displayed picture up to bandwith-resolution limiting of the monitor (30 megahertz) or the buffer (10 megahertz) and the 873 line scan format. The television monitors are provided with a polarity switch allowing the users choice of black on white, or white on black, formats.

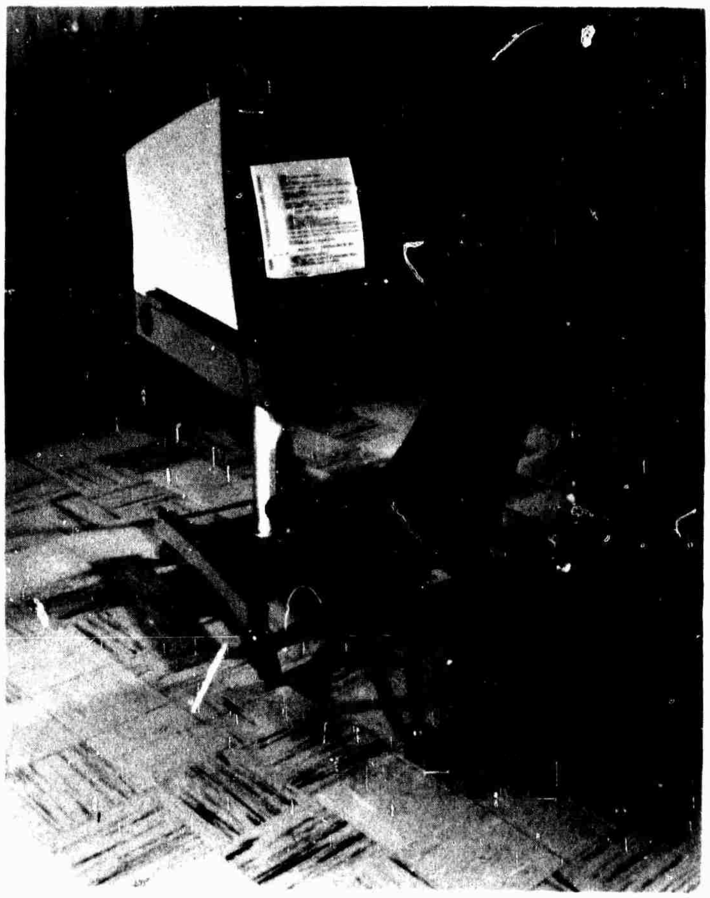

Fig. 4 –View of model Video Graphic console configured with slideout keyboard for adjustable work space

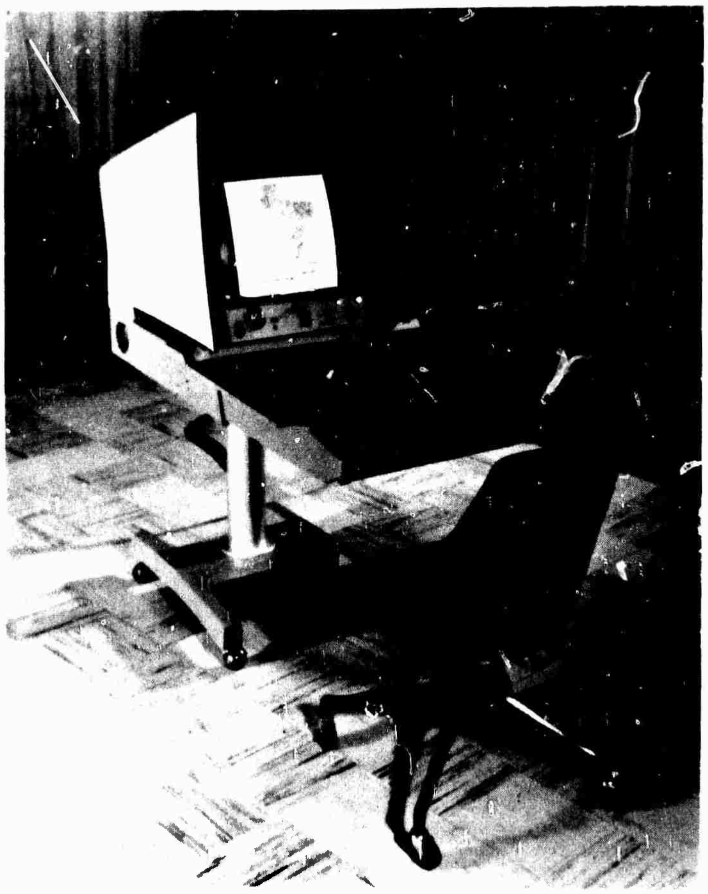

Fig. 5—Video Graphic console with tablet on keyboard work space

SYSTEM PERFORMANCE

The major design criteria enable the system to be sufficiently responsive and sharable that any of several concurrent users can utilize an interaction capacity appropriate to the problem. The averaging power of concurrent users allows appropriate economic sharing of the hardware. Uniform line-widths, uniform brightness, and line closure are important, and are state of the art.

Average character-generation time is 14 microseconds. Vector-paint time varies between 10 and 100 microseconds with a maximum depending on the vector length.

The picture generator will execute graphic orders at about an average of 70K bytes/sec. The paint time of the scan converter is a function of picture complexity, but averages 10 milliseconds. The upper limit of the scan converter storage time is about 700 milliseconds allowing very complex pictures to be written. Since flicker rate is unrelated to paint time, there are essentially no picture-programming restrictions imposed on the users.

System performance with three scan converters will support eight to ten highly interactive stations, each with unlimited input rate from tablets. The system can theoretically support over 150 stations operating only with keyboard text interaction. Of course, video buffer storage would have to be added for refreshing of pictures beyond the present 32-console limit. One would expect many environments to support dynamically some appropriate mix because even those demanding high interaction rates actually use their "racing stripes" a small percentage of the time. Currently, 25 stations are available for convenient use.

SYSTEM RELIABILITY, LIMITATIONS, AND PROBLEMS

The Video Graphic System was installed at Rand in October 1968. It has been operational virtually 24 hours a day, 7 days a week, since installation. The overall reliability has been remarkably good considering the analog nature of some of the hardware. Downtime has been trivial and maintenance requirements minimum. Preventative maintenance is limited mainly to a weekly check of scan converter adjustments for scan converter aging.

The 10-megahertz bandwidth per channel is the limiting factor in terms of system resolution and picture quality. To bring the system into balance from a system resolution standpoint, the buffer frequency should be 20 megahertz to match the limitation of scan converters. All other components, including the monitors, have a basic limit of 30 megahertz.

The buffer has two basic problems that must be solved for optimum, continuous tone-picture use. These are:

1. Low signal-to-noise ratio in some tracks, mainly due to incomplete erasure of previously written information. There is a need for either a separate erase head or a better erase with the present heads. This condition is achievable, but only through careful analysis and redesign of the head, and possibly the recording medium.
2. Detectable track-to-track interference during a write operation for some channels in the video buffer. Analysis has not yet determined enough about the source of the problem to suggest a solution.

SYSTEM USE

Thus far, most of the VGS use has been to support users performing research in man-machine communication. Thus, the VGS ability to provide real-time response of machine interpretation of human gestures (via Rand Tablet stylus-input device) is vital. This capability is used for such things as real-time automatic hand-printed character recognition, and to supply highly responsive full-graphic editing. However, the computer researcher and the programming staff of the Rand Computation Center also need remote job entry, program debugging, and program editing. These functions are currently supplied to users via IBM's CPS, retrofitted with a graphic interface (keyboard input and graphic display output), and a general-purpose editor called Simultaneous Graphic System (SGS).

In addition, the VGS is used extensively where problem-solving is enhanced by the use of superimposed computer-generated pictures and noncoded information from a television camera.

The following figures are pictures of displayed information representative of the kinds of system uses. Figure 6 shows a portion of a displayed "pag " of program-

```
10.     plot:    DO ;
20.              DECLARE p(0:30) CHAR(40),y(41),symb CHAR(1);
25.              DECLARE z(41);
30.              LET f(x)=sin(x)*exp(-x/10);
31.              LET g(x)=cos(x/2)/2;
35.              p=' ';
40.              PUT LIST('Statements 30 and 31 define f(x) and g(x).');
41.              PUT LIST('Enter xmin, xmax or "," for 0 thru 2I');
50.              GET LIST(xmin,xmax);
60.              dx=(xmax-xmin)/40;
70.              symb='*';
71.              ymin=f(xmin);
72.              ymax=ymin;
73.              x=xmin-dx/2;
74.              DO i=1 TO 41;
75.              y(i)=f(x);
75.5             z(i)=g(x);
76.              ymax=max(ymax,y(i));
77.              ymin=min(ymin,y(i));
78.              x=x+dx;
79.              END ;
81.              PUT IMAGE(ymin,ymax)(image);
82.              GET LIST(ymin,ymax);
83.              dy=(ymax-ymin)/30;
84.              l=floor((z(1)-ymin)/dy+.5);
85.     plotit:  DO i=1 TO 40;
86.              m=floor((z(i+1)-ymin)/dy+.5);
86.5             IF l¬=m THEN l=l+sign(m-l);
87.     ploop:   IF l>30|l<0 THEN GO TO plop2;
87.5             substr(p(l),i,1)=symb;
88.     plop2:   IF l=m THEN GO TO done;
89.              l=l+sign(m-l);
90.              GO TO ploop;
91.     done:    END ;
92.              IF symb='o' THEN GO TO putit;
                         MODE=REF UP      STATUS=UPPER PAGE FULL
list;
```

Fig. 6—Sample of CPS program text printed on screen at 74 characters per line by 52 lines per screen height

ming text used with graphic CPS. Figures 7 and 8 show the application of VGS to the photo interpretation process used by the intelligence community. The display shown in Fig. 7 is a composite of an image from a television camera (image) looking at a photograph and user-described annotation that is digitally generated as a result of tablet-stylus action. The right side of the picture shows a column of computer-generated "display buttons" that allow choice of line-brightness, line-width, or solid or dashed lines to permit on-line annotation of the picture via the Rand Tablet stylus used as the input device. For this application there is generally no need to digitally store the complex picture. Annotation is user-generated, based on features important to the interpreter. The annotation is generated on-line, stored on-line, and is available for later review; or a transparent hard copy overlay can be generated by a film recorder to use with the original photograph.

Figure 8 shows some resultant annotation retrieved from on-line files.

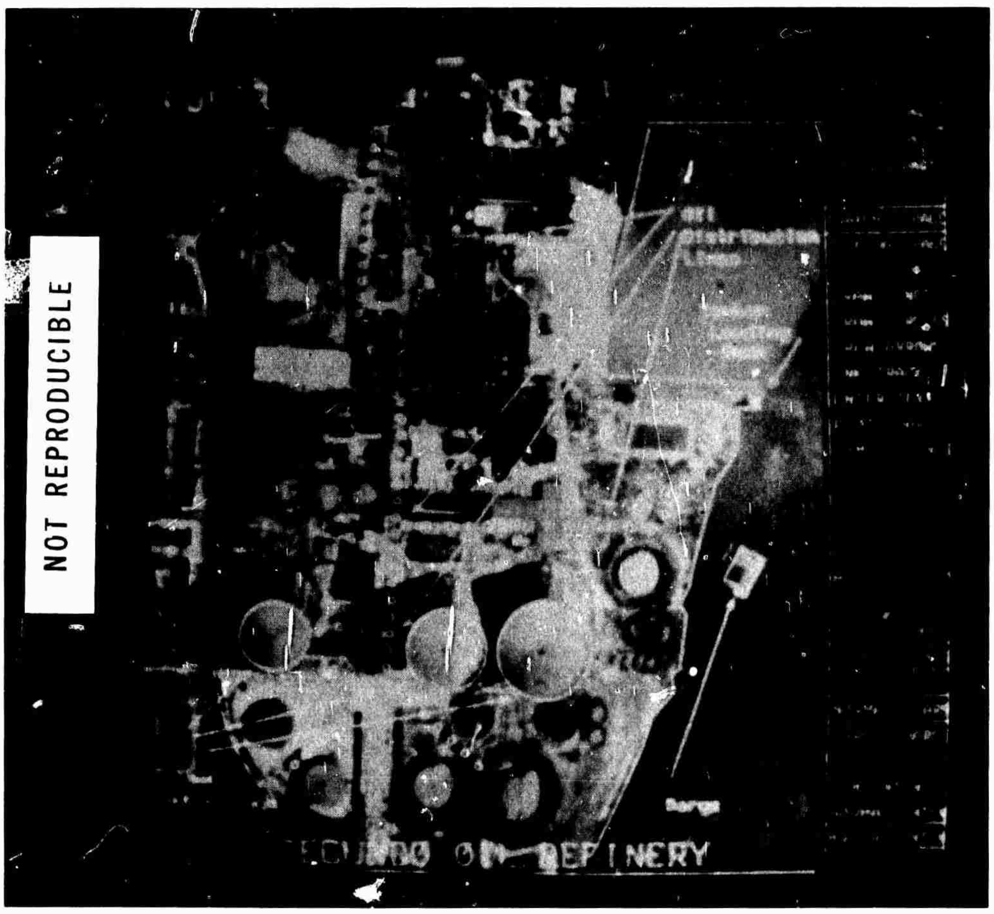

Fig. 7—Close-up of video display of a superimposed natural image and computer-generated display described via the tablet and keyboard

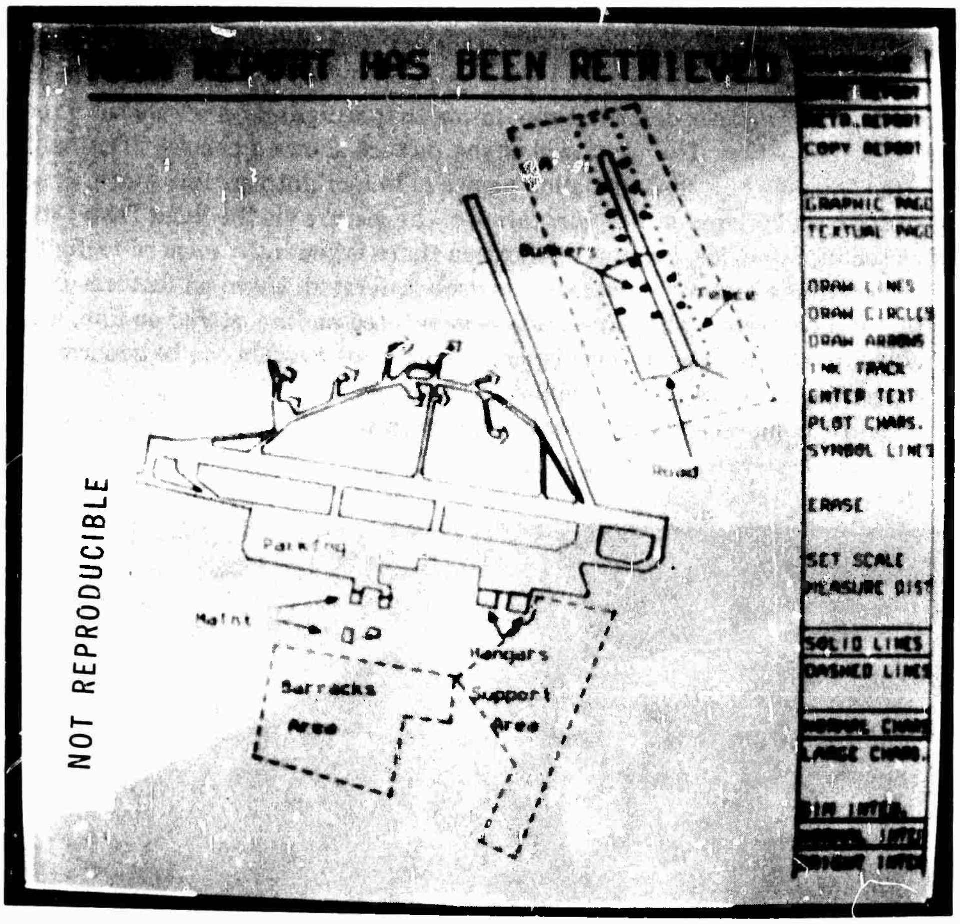

Fig. 8—Close-up of video display with a picture from an aerial photo annotation report application

SOFTWARE

The software design carefully reflects the kind of flexibility available to each user, and provides the virtually transparent access method required to keep the user focused on the solution of his problem, and not on the mechanics of the access.

A basic software-access method is used to communicate with the computer and any service resident in any computer. The software is supportive to simple key entry uses as well as complex, highly interactive applications. The software has been designed to assure the greatest possible exportability with the IBM System 360 Operating System.

The software reflects the completely terminal-oriented VGS, and provides the user the ability not only to flexibly and easily obtain an interaction level, a specific computer, a specific language, and a specific input device, but also to be charged according to the level of service provided.

The three system software packages are the Video Message Handler, the Integrated Graphics System, and the 1800 software. Discussion of the software is limited to a very brief description of each system along with a statement of its current status.

VIDEO MESSAGE HANDLER (VMH)

The software resides in a general OS multiprogramming environment operating under IBM MFTII or M.V.T. as a partition or task. Its major functions are:

1. To support a multiuser environment and to act as the general communication agent for each user;
2. To create, manage, and police terminal-to-program and program-to-terminal connections according to requests on the part of terminals and programs;
3. To receive, queue, route, and concentrate messages to and from the 1800;
4. To manage and distribute control messages.

VMH has been implemented and is currently operating in all three connected service machines. It acts as the sole access method for all on-going application-level programs in their use of the Video Graphic System.

INTEGRATED GRAPHICS SYSTEM (IGS)

IGS is a graphic subroutine package callable from PL/1 or Fortran [6]. It is OS compatible and display-device independent (i.e., it can support the IBM 2250, the VGS terminals with several input devices, and the Stromberg Carlson 4060 hard copy recorder). The language allows transfer of existing programs to the VGS from the IBM 2250 with no change. Presumably the reverse is true too; however, it is untested.

The IGS package currently supports all former 2250 display calls and input-device management and messages except for the character-recognition package associated with the tablet. Currently the latter is being implemented and a large portion of IGS is being revised to be reentrant for more efficient multiuser use.

1800 SOFTWARE

The 1800 software is treated by users as an extension of the hardware. The primary function of the 1800 is to set up, protect, and manage traffic through the terminal-service machine logical information flow paths. Other functions relate to error analysis and recovery, rote task, and high interrupt-rate processing and buffering to relieve service machine loads.

An example of the latter is the single-line text-editing function performed by the 1800. One of the ways that a service machine program may unlock a terminal keyboard (allowing character input) is via a command to the 1800 to accept initial contents, display, and update a given text line as modified by individual key strokes at the keyboard. When a "return" key is struck, the keyboard is physically locked and the 1800 sends the resultant text line back to the service machine. Thus, the service machine sees just one interrupt per line rather than at each key stroke. Since the 1800 software system design is optimized for this type of job, it can handle many such tasks with very quick response, allowing a multitude of simultaneous interactive displays.

The 1800 software has been running for about a year, essentially 24 hours a day, 7 days a week, supporting all of the devices described as well as regular maintenance functions. Revisions are currently being made to support a connection to the ARPA Network and some experimental terminal devices.

CONCLUDING REMARKS

The Video Graphic System is one approach to general-purpose graphics. The use of such a system is most productive in an environment where at least 5 to 10 concurrent users are expected to work. To keep the installation cost of consoles at a reasonable level, each console should be located within a 3000-foot radius of the shared central facility.

At the time the video system was implemented, the analog approach to scan conversion and buffering was mandatory to achieve the cost-performance criteria established during the design phase.

With the current impressive cost performance of integrated circuits, an all-digital approach to a video system appears to be achievable with only modest development effort. We are currently in the process of designing a digital version of the Rand system.

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