ETL-0035

THE AEROSPACE CORPORATION

SURVEY OF

DIGITAL IMAGE DISPLAY SYSTEMS
(SOFT COPY)

by

C. L. Patterson

June 1976

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
ETL - 0085

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
SURVEY OF DIGITA IMAGE DISPLAY SYSTEMS (Soft Copy).

5. TYPE OF REPORT & PERIOD COVERED
Contract Report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
C. L. Patterson

8. CONTRACT OR GRANT NUMBER(s)
F04701-75-C-0076

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Aerospace Corporation
P.O. Box 95085
Los Angeles, California 90045

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

12. REPORT DATE
June 1976

13. NUMBER OF PAGES
63

64p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The survey in this report is directed toward the CRT display systems in order to assess the current state of interactive display systems. This report goes further than previous surveys in that monitor systems were reviewed independent of the total systems. Another primary element in the digital image display system the refresh technology used by any system. This report pays particular attention to the refresh technique. The results show that most new developments in the field were predicted, such as solid state memory for refresh of the monitor and the appearance of a new '1000'line monitor from two suppliers.

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Acknowledgment

The survey of digital image processing display systems reported herein was performed at the request of the Engineering Topographic Laboratories. Personnel having cognizance of the effort from The Engineering Topographic Laboratories include:

Mr. W. Boge	Contract Monitor
Mr. L. Gambino	Computer Science Laboratory
Dr. B. Schrock	Computer Science Laboratory

Forward

The survey reported herein is one of a series prepared for the Engineering Topographic Laboratories as an aid in the development of a major digital image processing facility. The other volumes in the series include:

1. "ETL Computer Facility Optimization Study", by D. J. Theis, June 1976
2. "Survey of Display Devices (Hard Copy)", by C. L. Patterson, June 1976
3. "Survey of Digital Image Scanning Systems", by M. M. Irvin, June 1976
4. "Software Studies", by G. Buechler, June 1976

INTRODUCTION

Digital processing of images generally terminates with the display of the data to the human user. The final result (display) can take any of several forms, including: film images of the processed data (hereafter termed hardcopy): alphanumeric display of data such as statistical properties of the data both before and after processing or pattern recognition results or any of a host of word/number data sets a user might seek; or finally the image data might be presented in the form of a cathode ray tube (CRT) device (hereafter termed "soft copy"). Display of the digital image data is the most critical element in the image processing system as it must accommodate the visual system of the human user, and, as one might expect, the display must allow a wide variety in user properties. The flexibility of the display system is very difficult to specify due largely to the lack of knowledge existing in the area of the human visual system (especially the variability between users). Obviously, the lack of knowledge is particularly severe if a gray scale image is the object to be specified. As a result of the difficulty with the display of image data, many organizations within and without the government have looked to the "interactive" devices as the ultimate display. By the term interactive is meant that the user may vary parameters in "real time" to produce images which allow the most efficient use of time and the user's interpretative capabilities. The real time, interactive system is very difficult to configure for systems which do not rely on the CRT devices.

The survey reported herein is directed toward the CRT display systems in order to assess the current state of interactive display systems. Perhaps of equal importance is the desire to determine the manufacturers' motivation in parameter selection in the development process. For example, why did the manufacturer select a particular monitor system? Or why was a certain trackball (or joystick) cursor configuration selected. Unfortunately many of these kinds of questions have no real answers other than the design engineer happened to like what he saw. Since few, if any, of these design engineers have experience as photo-interpreters, then the validity of some of these parameter selections might be questioned.

The survey of digital image display systems reported herein went somewhat further than have previous surveys in that monitor systems were reviewed independent of the total systems. It was believed by the tour members that the monitors were a very critical link which had been ignored in the previous surveys. It should be noted that the number of monitor manufacturers is very large and that it would have been a very large task to survey all. However a representative sample was selected to start to determine what could be learned which would be of long term assistance. In particular, there was a strong interest in the future developments which are in the planning stage.

Another primary element in the digital image display system is the refresh technology used by a particular system. The CRT systems normally require that the displayed data be re-displayed at some periodic rate such that the data does not have an apparent flicker, that is, the image should appear stable and stationary on the display screen. For the digital systems the re-display or flicker is a particular problem since it requires very high data rates. From commercial television studies it has been noted that the data must be re-displayed at a rate of 30 times per second which in turn implies data rates of hundreds of megabits per second. The refresh techniques have accounted for a large amount of the cost of digital image display systems. The current technology has used digital disc techniques for the past three or so years but the advent of solid state techniques is nearing. The promise is for decreased cost and improved capability. As a major element in this survey, the tour group paid special attention to the refresh technique. It was decided that a special survey was not warranted at this time due to the large number of solid state memory systems available.

SURVEY TECHNIQUE

The softcopy display survey technique was a composite of direct manufacturer in-plant visit and detailed review of manufacturer documentation. A literature search preceded all activity to ascertain which organizations were in the display system manufacturing field. Each manufacturer identified was then contacted by telephone and asked if they were willing to participate in the survey. If the organization did express an interest, then they were requested to transmit any applicable descriptive literature (specifications, theory of operation, etc.) to the writer for a preliminary review. This last step was of particular importance since it allowed the survey group to eliminate any unnecessary or inappropriate systems and ultimately reduced the travel required, and allowed an intelligent question package to be prepared.

Following the preliminary review, the remaining manufacturers were contacted again for a specific appointment for an in-plant review. The added dimension of an in-plant review was of particular importance in the area of soft copy display in that the end objective is viewing of image data. It was felt that without actually viewing the display device the survey would have been weakened.

A survey team was selected to actively participate on the tour of sites and to review the applicable literature. The survey team consisted of the following members:

Dr. H. C. Andrews	Consultant to The Aerospace Corp.
Dr. J. Boothe	The Boeing Co.
Ms. M. M. Irvin	The Aerospace Corp.
Mr. C. L. Patterson	The Aerospace Corp. (Tour Leader)

Dr. Andrews was asked to participate on the basis of an extensive background in digital image processing techniques and systems. Dr. J. Boothe was selected on the basis of an extensive background evaluation of psychological testing of photo-interpreters in facilities using digitally processed images. Ms. M. Irvin was asked to participate on the basis of an extensive background in the operations associated with digital image display (she is currently the operator of the Aerospace Digital Image Processing Facility).

After each organization was visited, an informal debriefing of the tour members was conducted by the tour leader for inclusion into this report.

Results of the tour and document review indicated several methods of classifying the devices reviewed. The outline below indicates the method actually chosen for the classification of devices.

I. Monitor systems: defined to consist of the actual viewing screen and associated drive electronics.

II. Display systems: defined to consist of the following items required to support just the display system exclusive of computers, mass storage, software, etc:

a. Monitor device
b. Refresh Hardware
c. Track ball or joystick is included
d. Point processing technique

III. Stand Alone System: defined to consist of the following components:

a. Display System (as in II.)
b. Computer System
c. Mass Storage Device (tape unit and/or disc system)
d. Command Terminal
e. Software System

IV. Peripheral Devices: defined to consist of the added devices which are not required for processing or display of images. The devices might include the following:

a. Projection Devices
b. Scanning and Digitizing Devices (which are to be surveyed in a separate report)
c. Special purpose hardware, such as FFT (fast Fourier transform) components.

Peripheral devices as described in item four were not the objective of the survey and were covered as the various manufacturers desired. (Each manufacturer was allowed to present any material desired to the group within a four hour tour of the appropriate facility.) Tour members were instructed to avoid "leading" the manufacturer by questions other than those required to clarify performance of the display devices. Very little comment will be made regarding the peripheral devices shown to the tour group.

Another technique for classification of the display devices was that of beam vs. matrix addressing. The addressing techniques were very limited in that only beam addressed systems were seen in the tour. The implication of direct matrix addressing of the display is very interesting and may well be a viable technique for the future. A more detailed discussion will be presented in a later section.

A key point to be made on the survey technique is that a large number of potential suppliers of digital image display systems were not covered. The reasons for bypassing these potential suppliers is that they either did not respond to the inquiries made during an early period, or that they were very remote and would require a significant investment in both cost and time to cover. Neither cost nor time were available in large quantity. With the caveat in mind that the results were limited in quantity, it is believed that the survey discussed herein is relatively complete in terms of the types of systems available, general performance characteristics, and technologies utilized.

DISPLAY SYSTEMS SPECIFICATIONS

No specific sets of soft copy display systems specifications were available to the survey group at the time of the survey. However, it seems particularly appropriate to make some comment regarding system level specifications.

Development of system level specifications will require several pre-cursor steps prior to the development of reasonable specifications. At the first level, operational scenarios will be of great value. These scenarios are, in essence, an answer to the basic question, "how is the display to be used?". The question may seem trivial on the surface, but in reality, is very difficult. A thoughtful answer will include a careful review of the operational needs of the user. Specific questions which are implied include:

a. What kind of imagery is to be processed?
   1. What is the required resolution in sampled form (i.e., how many pixels are required?)
   2. What is the dynamic range of the imagery to be processed?
   3. Is color a factor in the original imagery?
   4. What kind of collateral data is to be used?

b. What operations are to be performed on the display equipment?
   1. Is the display to be used in a production environment?
      a. What throughput time is needed?
      b. What technical functions are needed?
      c. What qualifications will be available for the operator?
   2. Is the display to be operated in a research and development environment?

c. What kind of general purpose (or special purpose) computer is to be used?

Up to this point the only concern which has been expressed by the user is that "3000 by 3000 pixel" images are the least that will be required, throughput time (defined here as the time to put an image from some mass storage device to the display screen) of less than a second. To the engineer these comments seem irresponsible, since the capability sought lies outside of the current capability of the community. Yet the implied requirements have substance and they must be addressed.

Many of the systems which have been developed and employed in various operating environments were not strictly specified by the end user. The systems were the product of the engineering judgement of the developer. Interaction with the ultimate user or the photo-interpreter was highly limited. As it was stated earlier, if it looked or seemed good to the engineer or programmer, then the function in question was included. If it seemed unreasonable then the function in question was ignored. In many instances it would seem that alternate solutions should have been sought. As an example, consider the problem associated with the resolution of the device. Until very recently, the highest resolution color monitor would not support more than 512 x 512 image points. The users, on the other hand stoutly defended the need for a 3000 by 3000 data point display. The psychologist would agree that the human visual system will not use more than 500 x 500 displayed points due to resolution limits. It is assumed that the user is particularly concerned with the search problem where the image context is of great value. One solution which seems to offer promise is the use of a degraded image as a search field with the high resolution data stored in a rapidly accessible form and a mechanism of extracting any 512 x 512 designed by the user. In this approach, the user would search the low resolution image, and when (or if) something interests him, then by the appropriate pointer and command, the system would fetch a high resolution image for detail study. In this case, the display system and associated computer would act as a microscope for the user. Hence a minor modification of the operating scenario would result in both a practical system from the engineering point of view and at the same time provide the required capability to the photo-interpreter. It would seem that many of the conflicts could be resolved by similar "trickery".

In summary, there are no usable specification currently available to the manufacturers. If operating scenarios are available, then it might be appropriate to begin exploration with the various manufacturers to determine what requirement/specifications can be developed to allow a new class of digital image soft copy displays to be developed which will meet the long term user requirements.

SURVEY RESULTS

Results of the survey performed are summarized in this section. Details are omitted as they are deemed unnecessary to show the characteristics of the devices. If detailed information is required, then specification sheets can be made available. It was initially planned to attach these detail data sheets as an appendix to this report, but the detail sheets seemed to add very little to an understanding of the systems involved.

Organization of this section of the survey report is based on reporting the monitor survey first, followed with the display systems, followed by the standalone systems. Each device included in the survey is further summarized in a chart for rapid comparison. It should be noted that these systems were reported on a briefing given in Washington, D.C. on 19 February 1976.

Monitor Systems

Monitors utilized on the various digital image display systems are the major oversight of previous survey teams. The current survey has yet to perform a comprehensive review of monitoring systems. In preliminary conversations with several manufacturers of the display systems there was an indication that the primary monitor was manufactured by the Conrac Corporation. The primary reason for each of the manufacturers choice of Conrac monitors was the fact that Conrac is the standard television broadcast studio monitor. It was claimed that the monitor was the highest quality available. As a result Conrac became the primary review source. Other manufacturers were considered, but limited funds and time precluded detailed review. Most of the other firms involved were primarily commercial and basically span the home television market. Conrac did on the surface appear to be the standard that most broadcast organizations employed. In addition to the Conrac system which was surveyed, two other manufacturers of black and white monitors were reviewed. These included Hughes Aircraft Co. and Sierra Scientific Corporation. In addition to the noted companies surveyed, we also considered a new Japanese monitor built by Chormussen Ltd. of Japan. The monitor is, however, not available in the United States.

The monitors surveyed are believed to give a realistic insight into the current state-of-the-art in monitor systems. Each of the monitor manufacturers surveyed will be discussed in the following paragraphs.

Conrac Corp. Monitors

Conrac Corporation manufactures a broad range of television monitors principally directed toward the professional broadcast studio. Many of the manufacturers of digital display systems utilize the Conrac monitors. In particular both Comtal and International Imaging Systems, Division of Stanford Technology Corporation, use the Conrac RHN series in their respective display systems. The primary monitor system of interest at the time of the tour was the color monitors. Conrac manufactures two versions of the basic color monitor which are heavily used in the digital display field. These include the RHN series and the RHB series. The RHN systems are an RGB input type while the RHB systems are a standard NTSC color input system. Only the RHN series will be discussed herein. In addition Conrac manufactures a series of other monitors, both color and black and white. The other color receivers are either of a lower quality for educational use or are of a higher quality but utilizing the PAL (B or M) color input common to the European and South American television systems.

Conrac's address and telephone number are given in the Appendix for those who have a more detailed interest in the specifics of system operation.

Some of the basic specifications of the RHN monitor are given in Table I. The basic monitor is supplied in 19 inch, 22 inch, or 25 inch monitor sizes. The basic tubes are of an RCA manufacture and are of the shadow mask type. The shadow mask tube supplied as a standard has a basic triad spacing of 0.024 inches with a spot size of 0.007 inches. The tube deflection angle is plus or minus 45 degrees (that is, a 90 degree tube). The normal tube is adjusted for a 4 by 3 aspect ratio but can easily be set for a 1 by 1 ratio. Both Comtal and International Imaging systems do adjust for the square raster.

A tour of the Conrac facility was a very instructive expenditure of time. It was learned that Conrac does have the capability of manufacturing their own tubes, although at this time, the only tubes manufactured are black and white. Little was learned, however, regarding the phosphors which Conrac uses. It was claimed that the process is proprietary. On the other

Minimum TV line resolution (at 20 foot-lamberts)

485 at the center of the tube

390 at the corner of the tube

Linearity	plus or minus 2% of the raster height
Color Temperature	6500^{o}K (illuminate D) The color temperature is adjustable to suit the user.
Input Color System	Red, Green, Blue (RGB)
Tube Type	Shadow mask (0.024 inch triad spacing)
Spot Size	0.007 inch (0.003 to 0.004 inch available on special order)
Video Bandwidth	Flat to 10 MHz plus or minus 0.5 db on each of three channels.

Table I

Conrac RHN Color Monitor Specifications

hand it was learned that Conrac does have the capability to manufacture all other components of their monitor systems including the deflection coils. In general, the tour team was highly impressed with the quality control demonstrated by the Conrac operation. It should be noted that the quality is the primary reason for the relatively high cost of the RHN monitor associated with the commercial system (the price for the RHN directly from Conrac ranges from approximately $3800 to $4200 depending upon monitor size).

Several new developments were discovered during the tour of the Conrac facility. The first, and perhaps the most significant, is the development of a new "1000" line monitor based on the MGA tube (Mitsubishi). The MGA tube uses a 0.012 inch triad spacing as compared to the 0.024 inch triad spacing of the RCA shadow mask tube. The development will perhaps stimulate the development of a complete 1000 by 1000 digital display system. Even if the development of display is not forthcoming, the new tube should produce considerable improvement in the 512 by 512 display systems now in use. It is understood that Comtal Corporation is in the process of reconfiguring (a relatively minor task) their 512 by 512 display systems to utilize the new higher resolution tube. It would be recommended that any new procurements seriously consider the high resolution color system. Conrac indicated that the approximate cost of the new monitor would be approximately $6000 as compared to a cost of $4000 for the RHN monitor. With respect to the new high resolution Conrac monitor, Conrac did make several negative points. Conrac claims that the color control and white uniformity (between tubes) is relatively poor although no measurements were presented to substantiate the claim. The problems of white uniformity and color control should prove troublesome unless several monitors are planned for a common viewing area (that is one photo-interpreter viewing both screens at the same time). Even in this case, it would be wise to perform measurements to evaluate the effect of any mismatch.

The next major new development observed at the Conrac facility is a new convergence system in test. The convergence of the older monitors has been a particularly troublesome problem. Even well trained technicians find the convergence difficult (in fact the writer has rarely seen a well converged system in operational environments). The new convergence system will allow a relatively untrained person to perform the convergence with a minimum of difficulty. The past problem has been to perform the convergence over the entire tube face. It is relatively easy to converge near the center of the tube, but almost impossible to keep or drive the convergence into specification at the edge of the field. The new convergence system will allow the operator to adjust the convergence for each of 9 separate regions of the tube face independently. A detailed explanation of the procedure will not be given here, but it should be noted that the new system will be well worth serious consideration in future display system procurements.

Hughes Aircraft Company

Hughes Aircraft Company (HAC) has for the past three or so years been involved in the development of a "high resolution" display monitor. Funding for the effort has been both from federal sources and HAC IR & D funds. The basic objectives have been to produce a display monitor which will display up to 2048 by 2048 picture elements with up to 8 bits of gray scale.

No documentation was made available to the tour group. (It should be noted that only M. Irvin and C. Patterson were present for the HAC demonstration as the instrument does involve some HAC proprietary material.) The basic monitor produced a "green" and black image which was very "crisp" in appearance. The contrast appeared very high. The demonstration was not really complete as only a 932 by 2048 image was shown due to refresh limitations.

The basic purpose of the tour at HAC was to examine some of the purely military display technology, and to determine what research is currently on-going.

A summary of the characteristics of the monitor is shown in Table II.

Image Size:	2048 x 2048 pixels (932 x 2048 pixels demonstrated)
Resolution:	Modulation of 0.6 at 100 lines/inch
Display Size:	10 inch by 10 inch (4.7 inch used)
Phosphor Type:	P43

Table II

Hughes Aircraft High Resolution
Monitor Characteristics

As a general conclusion, it seemed that several additional years of development are required before any reasonable system will be available.

For those who may be interested, the device is being developed by

Hughes Aircraft Company
Fullerton, California

The person responsible for the development is Mr. Peter Baron at the above organization.

Sierra Scientific Corp.

The final monitor manufacturer reviewed was Sierra Scientific. The primary activity at Sierra is development of monitors and cameras (vidicons) for use in the biomedical community. No particular system was demonstrated during the visit.

The principal monitor discussed during the tour was the Sierra Scientific mode HD 1501 which was claimed to have the characteristics: shown in Table III.

Tube Size:	15 inch diagonal
Spot Size	0.008 inch (0.004 inch available at extra cost)
Video Bandwidth	30 MH_z
Resolution:	1500 Television line pairs at the tube center 1300 Television line pairs worst case
Phosphor:	P4 (11,000^{o}K color temperature)
Cost:	$2500 (add $1000 for the 0.004 inch spot)

Table III

Sierra Scientific Corporation Model HD1501 Display

It should be noted that the device discussed is strictly an analog instrument. The additional digital hardware to make the system compatible with image sources of interest in this report are not considered.

In discussions with Mr. Gilblom the question was raised as to the feasibility of a very high resolution CRT (of the order of 2000 by 2000 resolution elements). The response was very interesting in that it was taken seriously. Gilblom stated that he felt such a tube could be constructed now. However, the solution would lie in the penetration beam technology. He also noted that he had heard of the Mitsubishi tube but that they were near the current limit of the shadow mask technology. As to the beam penetration tube, Gilblom indicated that he believed that one of the Dumont subsidiaries was involved in such a development. (In later reviews, it was determined that the tube was available now from Dumont and is manufactured by Thompson CSF in France).

Display Systems

Display systems which were defined under the section titled Survey Technique were surveyed by both document review and in-plant tour where it was felt the physical viewing of the equipment would be of value. As in the case of the monitor review, it is believed that the survey is not complete, but it is also believed that the systems reported herein are representative of the current state-of-the-art in display technology.

Survey techniques were much the same as that used in the monitor systems in that the survey began with systems which were familiar to the tour team members. In particular, considerable interest has been shown in the Comtal systems as many of their instruments are currently in use by a wide variety of facilities. However, Comtal has introduced a series of "new" systems and improvements on the older devices, hence a re-survey of Comtal was clearly warranted. In addition to the Comtal devices, there are a number of similar systems which have been in use for several years including the IPADS (Image Processing and Display System) built by Aeronutronic Ford, a series of display systems built by Dicomed Corporation, and the CRT display devices built by Ramtek which have been implemented into the ERIM facility. In addition to the more well known devices, there are a host of devices which are manufactured by lesser known organizations which would warrant a close review. It is in this latter area that the survey is most obviously deficient. It is almost impossible for all of these other organizations to be included in that they are not known to the writer. Yet, it is these smaller organizations which are the most likely to produce innovative solutions to the softcopy display problems which are facing the image processing community. As an example, one of the smaller companies, International Imaging Systems (a subsidiary of Stanford Technology Corporation), has developed an extremely flexible and powerful processing system which should be of great interest to any organization involved in digital processing of image data.

Each of the systems surveyed will be described in the following paragraphs. Detail "fact sheets" will not be included as a part of this report, but if the reader is interested, the manufacturer addresses are included in Appendix A for reference.

Aeronutronic Ford

Aeronutronic Ford is a broadly based electronics and defense company which has had a long standing interest in digital image processing. Among the accomplishments of the Aeronutronic Ford activity in digital image processing, is the development of the IPADS device. In many respects the IPADS device contains elements of future systems. As an example, IPADS is the first display system to utilize a solid state memory to refresh the monitor. The system is also the first to claim a display capability of 1024 by 1024 image size in color. With respect to this latter point, it should be noted that the system produces only 3 bits amplitude in each color plane. Regardless, the problems of wide system bandwidth still had to be addressed. (It should be noted that the bandwidth of the system described is of the order of 100 megahertz--not a trivial problem).

A brief review of critical display system parameters is shown in Table IV.

Display Technique	Sequential Color
Image Size	1024 by 1024 pixels
Amplitude	3 bits per color
Refresh Rate	180 Fields per Second
Refresh Technique	Solid State
System Interface to Honeywell DDP 516	

Table IV
IPADS General Characteristics

The IPADS system as demonstrated to the writer and the tour group was interfaced to a Honeywell DDP 516 Computer which is a 16 bit parallel machine and include 12K words of memory, a magnetic tape input system and a 48 M bit disk storage system. At the time of the plant tour, Aeronutronic Ford was in the process of interfacing the IPADS to a Digital Equipment Corporation (DEC) PDP 11/45 system. Specific details of the interface and machine characteristics were not made available to the tour group.

The basic display technique used by Aeronutronic Ford is that of sequential color. A single "white" phosphor CRT provides the input light source. A tri-color filter wheel is located in front of the CRT to provide the color desired. Each of the three frames, one for red, one for green, and one for blue are written in time sequence with the color wheel being indexed between successive frames. The resultant image is projected, optically, to a viewing screen for the eventual operator use. The sequential color is unique among the systems covered in this survey.

IPADS has a number of interesting features in addition to the large image capability and solid state refresh. Specifically, the system employed a "touch point entry" technique to implement a number of processing operations. The "touch point entry" consists of an array of photodiodes and Light Emitting Diodes (LED) around the periphery of the viewing screen. The operator could break the beam between the LED and the photodiode causing a digital word to be generated for use in the computer. Aeronutronic Ford used the technique to select pseudo color assignments, local area definition for equalization, and a host of operations necessary in image processing problems. The specific algorithms activated by the touch point entry system will not be reviewed here as they may not be applicable to long term goals in the ETL facility but the technique may be of some interest as a generalized input to the display computer.

Refresh memory based on solid state technology is particularly important in the acquisition of new systems in the future. Reliability and speed of response are the primary forcing elements. The memory used in IPADS is not based on the newer technology involved in RAM (random access memory) or CCD (charge coupled device) systems. The memory, developed by Aeronutronic Ford, is drawn from the shift register technology and is relatively expensive. Other display systems operating a disk systems for monitor refresh suffer primarily from response time due largely to disc latency effects. The refresh memory in IPADS is not necessarily that which would be recommended in this effort, but does provide a historial background for future developments in solid state refresh technology.

Problems noticed in the IPADS demonstrations are most generally associated with the display technique. In general the display suffers from a low brightness output. The actual output was not photometrically measured, but appeared dim to the tour group. The contrast seemed relatively low compared to the usual CRT systems. In addition to the dim, low contrast image problems in the tube appeared very grainy. Aeronutronic Ford personnel were asked if they had made any studies of the noted problems. It was stated that the current tube was the problem and that they believed that a new tube would fix the problems especially the grainy appearance. (In previous visits to the IPADS facility, the writer had observed the low contrast, low brightness problems where the other tube types were being used, and it is not obvious that all of the problems are "curable" by a simple tube change.) The major problem with the low contrast, low brightness seems to be more determined by the color wheel effects and the basic limitation of light output from the CRT. The losses in the filter would make a definite contribution to the low brightness effect.

Further details on the system performance can be obtained directly from Aeronutronic Ford.

System costs for the IPADS were not made available to the tour group.

The next Aeronutronic Ford System reviewed was the "3 Pack System". The basic device is a projection system capable of providing full color image on a large screen. The system consists of three independent CRT devices with separate lens and filter systerms. The red, green, and blue images are supplied to the respective CRT/filter/lens systems, and are eventually projected on a large screen. Resolution of the system was not quoted, but appeared to be of the order of commercial television.

An outstanding feature of the system was a clever digital image registration system which would allow the three images to be registered by a relatively untrained operator. The registration system would allow the operator to deform or warp the image to remove some amount of image distortion as well as register the individual color planes. The technique was claimed to be proprietary and was not described but seemed to be a smooth functional fit such as might be achieved with splines or moderately high order polynomials (such as third or fourth order). The demonstration consisted of writing a grid pattern in each of the three colors and warping the individual color lines to registration. A capability for working over limited regions of the line space was also demonstrated. The technique may have application in other types of displays as well and is worth a follow up visit for additional details.

The brightness of the display was relatively low and was of concern to Aeronutronic Ford. A system, called "6 Pack", using 6 CRT/lens/filter combinations was in construction. The system was not demonstrated, but it was claimed that the added CRT devices would produce a sufficiently bright image.

Either 3 or 6 Pack systems might have application for certain tactical missions and would be worth further review for any such application which might arise.

A third system type was briefly discussed by Aeronutronic Ford. The system, called the Marine 3-D system, was developed for the purpose of a training simulator for ship pilots. The system produces a projected image which is 240° by 13°, and in full color. The system was not demonstrated to the touring group. No application is foreseen, at this time, for such a system.

Comtal Corporation

Comtal Corporation is a small corporation which has aggressively pursued the digital image display field for the past four or five years. The corporation began initially with the generic follow ons to a still older system, the Aerojet "Spectravision" (which is no longer being manufactured). The systems which are manufactured are based on a relatively straightforward approach of: a Conrac monitor (the RHN for the color system), a disc refresh system, a function memory package for point operations on the images, and a series of generally useful operations. The device is generally regarded as the current standard in the field and is regarded as a very flexible system for relatively moderate costs.

Three systems are of interest in this survey of the several currently manufactured (the term several is used here in that it is relatively difficult to distinguish between options and systems). Two of these systems are clearly display systems in the context of the definitions made under the section titled "Survey Technique", these include the model 8000 Color Image Display system, and the Model 1024 Display system. Each of the systems will be discussed in the following paragraphs. The third system, the Series 9, is a standalone device and will be discussed in the section Systems presented in a later section of this report.

A summary of characteristics of the Comtal model 8000 series is shown in Table V.

Functionally the Comtal model 8000 is a relatively straightforward system. Image data is written onto the Data Disc allowing up to 8 bits per image point per color plane. Image data from the Data Disc is presented to the function memory for any point operations. The function memory system is nothing more than a random access memory which is loaded from the host computer system with any desired remapping the user desires. The function memory remaps the image amplitude from the 8 bits input to the 6 bits output (8 bits as an option) with any piecewise linear gray scale the user desires. The pseudo color memory performs in much the same manner but assigning color to the specified gray levels

Monitor	Conrac RHN Color monitor
Image Size	512 by 512 pixels
Dynamic Range	6 or 8 bits (option)
Color	True (three) and pseudo
Frame Rate	60 Fields per second

Refresh System Data Disc with up to four image capability

Special Characteristics:

- Track Ball with programmable cursor
- Four function memories (one for each color plane plus one for pseudo color
- Scroll capability
- Graphics package available as an option

Interfaces to a relatively large number of computers

Table V

General Comtal Model 8000 Characteristics rather than a "new" gray scale. From the function memory the image data stream is given over to the digital to analog converters for conversion to the RGB (red, green, blue) analog data required for the monitor.

Since the time of the survey, several significant changes have been made in the Comtal model 8000 system. The first of these is the change in refresh memory. Comtal is now offering the Model 8000 with a solid state refresh memory technology. It was stated by Comtal that the price of refresh memory had decreased to the point that solid state was competitive with disc systems. It was stated that price would probably drop with the three image system using this technology. The writer has been led to believe that disc prices will also drop by a significant amount in the near future; however, it is rather early to assess cost changes.

The next change which is in work at Comtal is the changing of the Conrac monitor. As stated in an earlier section on the monitor survey, Conrac is now building a monitor using the Mitsubishi "1000" line tube (CRT). Comtal is planning to utilize the Mitsubishi tube based monitor in the basic model 8000 system (as an option). That is, using the 1000 line tube in a 512 line refresh device. The change will result in a dramatic increase in the quality of the display as this will allow the number of triads to be doubled for each pixel in the monitor. The change is well worthwhile since the current system is not strictly capable of delivering a true 512 by 512 display. The improved tube should allow a higher modulation transfer function for the display and produce much sharper images. The other side effects such as lack of color uniformity between monitors and the white uniformity loss will have to be assessed in an operational environment.

The next change worthy of note which has been implemented with the Comtal systems is the "burnt in" demonstration package. Comtal is producing a PROM (programmable read only memory) for use with their display systems which has the Comtal demonstration software for system control and operation. The PROM will allow the user to switch from a true software control to the PROM code in the event of software system failure or for any routine operations by the simple act of closing a switch. The functions included in the PROM device will not be discussed but may well be worth further investigation for any potential future procurement.

In general the model 8000 Comtal color display is a very flexible system at a relatively moderate cost. The system has been extensively used within the image processing community and as such seems to be the standard against which other systems are to be compared. Reliability has been reasonably good based on comments received from the various organizations using the device. Most of the complaints against the Comtal system have been associated with the monitor. In particular, the resolution is not 512 by 512 pixels using the RHN monitor. In all fairness, detailed resolution measurements have not been made on a large class of systems; it has been noted that a line pattern or grid with one pixel on and one pixel off cannot be resolved on most of the devices. Doubling the line or grid mesh, however, is generally resolved. In this sense, the resolution probably lies around 256 by 256. The new high resolution monitor will probably result in a significant increase in the apparent resolution of the system.

System cost is subject to a broad class of available options. However, it is estimated that the costs will lie between $50,000 and $90,000 for most commonly required equipment.

The next Comtal system of interest in this survey is the model 1024. The basic system design is a high resolution black and white display tube, a disc (solid state memory is probably available) refresh system, a function memory for point operations, track ball with a selectable cursor, and a graphic capability.

A summary of the characteristics of the Comtal Model 1024 is shown in Table VI.

Basically the Model 1024 is similar to the color devices manufactured by Comtal, using essentially the same technology. The only difference is that the system is designed for a black and white display. The monitor is the Conrac QQA. The tube was manufactured by Conrac. The amplitude dynamic range is from 4 to 8 bits (optional). Price range on the Model 1024 is between $50,000 and $85,000.

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Dicomed Corporation

Dicomed Corporation has been in the digital image processing equipment field for a number of years and manufactures a broad spectrum of systems ranging from display devices to scanning and hard copy playback systems. Two display devices from Dicomed Corporation are included in this survey. Both devices are based on the same kind of monitor technology, the dark writing electrochromic tube. The devices are unique in this survey in that neither require refresh (the monitors are a storage tube type). Properties of each are briefly discussed in the following paragraphs.

The Dicomed Corporation Model D-31 Image Display characteristics are summarized in Table VII.

Monitor Type:	Green and Black Storage Tube (dark writing electrochromic)
Screen Size:	8 inches diameter
Image Size:	1024 by 1024 Pixels
Point Intensity:	6 bits
Contrast Ratio:	3:1
Write Time:	40 to 100 seconds (full screen)
Registration:	plus or minus 0.12mm (0.005 inches)
Gamma correction capability	
Random point plot capability	
Pin cush distortion:	1.42 mm (0.056 inches) maximum

Table VII

Dicomed Corporation Model D-31 Image Display System Characteristics

The system described in Table VII was not seen by the touring group, however, most of the tour group was familiar with the model D-36 described in the following paragraphs and the two are very similar as will be shown by comparison of the characteristics tables. Costs of the system are not known but is somewhat less than that of the model D-36.

The other Dicomed Corporation display system is the Model D-36 Image Display. Characteristics of the D-36 are shown in Table VIII.

Monitor Type:	Green and Black Storage Tube (dark writing electrochromic)
Screen Size:	10 inches diameter
Point Intensity:	6 bits
Contrast Ratio:	3:1
Write Time:	120 seconds maximum (full screen)
Image Size:	2048 by 2048 Pixels
Registration:	plus or minus 0.21 mm
Gamma correction capability	
Random point plot capability	
Bounds plotting capability	
Quadrant addressability	
Pin cushion distortion: 1.78 mm maximum	

Table VIII

Dicomed Corporation Model D-36 Image Display System Characteristics

The similarity of the models D-31 and D-36 are easily seen by comparing Tables VII and VIII.

In a strict sense, the Dicomed systems described in the proceeding tables do not logically fit in the survey of this report in that neither device is interactive in the usually accepted definition. However, the storage systems are of some interest in that they do not require the expensive refresh system usually associated with the truly interactive systems. In addition, a major plus for the systems noted above is the relatively large image display capability, up to a 2048 by 2048 pixel image. The systems have been used by many (including the writer) as an editing tool. The large image is written onto the screen with an overlay grid. The interesting sections of the image can then be cropped out and used in the refreshed, interactive system.

Several characteristics of the storage tube systems which are of concern to the user have prevented a more extensive use of the general system type. The most obvious problem is the long time required to write a full screen image. In addition, to the long write time, the screen must be erased before any new image is written. The erase cycle adds to the turn around time causing a further drift from a real time, interactive system. A problem which has caused some difficulty is the finite life of the display tube. The screen has a life time of between 6000 and 10000 erasures (the screen is erased by heating). The replacement costs of the screen are between \$6000 and \$8000 (not including travel for the service personnel). Hence the user costs per cycle is of the order of \$1.00, which may not be insignificant in certain near production activities.

Perhaps the single largest complaint noted on the Dicomed D-36 systems is the screen properties. The contrast ratio of 3:1 is not completely satisfactory to many users. The low contrast coupled with the screen color (shades of "green") have caused many to complain of premature fatigue. It does not appear that the storage tube systems should be considered for detailed image interpretation, but rather for editing and co text review.

Costs for the Dicomed systems is relatively high in both instrument procurement and interfacing. The D-36 costs on the order of \$35,000 and the D-31 is somewhat lower. The interfaces are also expensive. In a recent procurement of an interface with a PDP 11/05, the interface came to approximately \$8000. It should be noted that the device has been interfaced with a large number of computer systems.

The interested reader should contact Dicomed directly for any further detailed information.

International Imaging Systems

One of the new entries into the digital image display systems is the International Imaging Systems Division of Stanford Technology Corporation. Since the International Imaging Systems (I^2S) is a relatively recent entry in to the field of image display, it might be expected that the systems which they are developing represent the most recent advances in the manufactured systems. In general, this expectation appears true. The systems available include two stand alone systems (which will be discussed in the appropriate section of this report) and a display console which is described in the following paragraphs.

The display system, which is termed the Model 70 User Console by I^2S is in essence the display portion of the stand alone systems described in following sections of this report. A summary of the characteristics of the display system is given in Table IX.

Monitor:	Conrac RHN color monitor
Image Size:	512 by 512
Point Intensity:	8 bits per pixel per color plane
Function Memory:	Both input and output for all three color planes, no special pseudo color function memory
Refresh Technique:	All solid state (Random Access Memory) allowing up to 13 512 by 512 by 8 bit images to be held in refresh memory
Special Functions:	A hardware processor is included prior to memory which will permit a large class of multi-pixel operations.
Trackball and cursor provided	

Table IX

Characteristics of the International Imaging Systems Model 70 User Console

The Model 70 Console summarized in the foregoing chart is one of the most interesting systems seen on the display systems tour. The system was designed, primarily for the Iranian government for use with LANDSAT data. Apparently, the development costs were paid for by the Iranian government.

Image data from the associated computer system is read into the model 70 Console after passing through an input function memory to perform any preliminary remapping on the image gray scale the user might want (it is not clear to the writer that the input function memory performs any useful function unless the user would like to perform a D log E correction prior to any subsequent operation). After the input function correction, the image data is made available to a special processor (I^2S referred to the special processor as an array processor, but it does not, strictly speaking, perform as the array processor commonly is understood). Operations from the special processor which have been programmed include the following class of operations:

- Hadamard Transform
- Karhunen-Loève Transforms on the spectral channels
- A fast classifier
- Arithmetic operations (element by element multiply, divide, add, and subtraction of the various images with or without weights)
- Histogram collection

The system routes the processed data to available memory. The memory system which is used as the refresh system, will allow up to thirteen images to be retained in refresh memory. The special processor has access to the refresh memory for operations as desired. The refresh memory feeds another set of function memories prior to digital to analog conversion and subsequent display on the Conrac monitor.

The abbreviated functional description covered in the preceding paragraph is somewhat of an over-simplification of the system, but was included to give the reader a brief understanding of the processing capabilities available in the I^2S Model 70 User Console. The interested reader should contact the manufacturer for additional details (see Appendix A for address and phone number information).

In addition to the system described above, the I^2S organization is in the process of investigation of the 1000 line monitor manufactured by Chormussen Ltd. (Japanese Corporation). Details of the monitor are not available at this time. I^2S obtained the monitor and the limited amount of data they had directly from the Japanese manufacturer. It was noted that the CRT is the same Mitsubishi tube that Conrac is using for their new monitor.

Interfaces for the I^2S Model 70 console are not as broad as could be desired. The system was designed to primarily function with the Hewlett Packard model 3000 computer. However I^2S has successfully interfaced the model 70 Console with a Digital Equipment Corporation PDP 11/45 system for NASA. Details of the system are not available at this time.

As a general conclusion, most of the tour group believed that the Model 70 Console is the most powerful display system on the market today. It was noted that the system is probably the system that most organizations will require within the next few years. All display manufacturers will most likely utilize the basic technology demonstrated by the I^2S system.

The only negative points which might be made is that of relative complexity. Some of the operations performed by the Model 70 will most likely not be desired by the operational photointerpreter (example, it would seem unlikely that most photointerpreters would know what a Karhunen Loève transform of spectral channels would do and would not be expected to make effective utilization of the capability). As stated earlier, the system is much like the other devices in the Display category, designed by engineers for engineers.

Ramtek Corporation

Ramtek Corporation is primarily a graphics display manufacturer which is also interested in the "gray" scale image display. At least one Ramtek image display system is in use by the image processing community (ERIM). The principal feature of the Ramtek display system is the solid state refresh memory using shift register technology.

A summary of the Ramtek system display is shown in Table X. Ramtek actually manufactures a series of display units. The systems shown here are those which are capable of supporting the gray scale image systems only. The systems are termed GX-100/200 series by Ramtek.

Monitor:	Conrac RHN
	(a black and white system is also available)
Image Size:	Up to a 512 by 512
	(Configured to suit the user needs)
Point Intensity:	Up to 8 bits per pixel
Refresh Memory:	Any amount desired
Random Vector Generations Capability	
Graphics Overlay available	
Trackball/joy stick and cursor	
Split Screen capability	
Scrolling capability	
Light Pen capability available	

Table X

Ramtek GX-100/200 Series
Image Display System Capability

The Ramtek GX100/200 systems are not as well defined as are the other systems seen on the tour. The system requires a more detailed specification from the user before a system is truly configured. The organization appears to have the capability to develop any desired configuration, but has not done all of the studies required to aid the customer. As an example, the function memory which is standard in most of the display systems seen was not specified in the Ramtek devices. The problems probably stem from the lack of experience in the handling of gray scale images. The system can be easily configured to be a duplicate of the Comtal 8000 series with the exception of the refresh memory. With respect to the refresh memory, Ramtek has been a steady hold out for shift register technology. They are now, however, seriously considering the use of CCD and RAM technology in the refresh system.

The Ramtek system could be an impressive device. However, a working gray scale system was not available for review. For those considering a Ramtek display system, it would be recommended that conversations be held with the Environmental Research Institute of Michigan (ERIM), as they are the only organization that the writer is aware of which is using the Ramtek system.

Costing of the Ramtek is relatively complex due largely to the lack of "preconfigured systems" for gray scale display. The system is expensive compared to the other devices reviewed due mostly to the shift register refresh memory. It should be noted that Ramtek quoted a price of approximately 0.78¢ per bit for the memory. On the basis of duplicating a Comtal like system, the Ramtek would cost approximately $150,000.

Other detailed information should be obtained directly from Ramtek Corporation. The address and phone is given in Appendix A.

Stand Alone Systems

It was felt that the display systems would be incomplete without a review of complete systems including a display device, computer, mass storage system, terminal and software. Many of these systems act as adjunct to the main computation facilities located at the various organizations involved in digital image processing. A very real possibility for the future image processing systems is in the area of distributed computing systems wherein the computational and data handling load is distributed between several machines, each optimized to handle a specific set of fuctions. It seems to make little sense, for example, to utilize a large scale computer to perform some of the relatively trivial operations commonly encountered in digital processing of images (such as gray scale remapping). In fact, in many cases, these trivial operations have a deleterious effect on the primary computing system in the sense the operations slow down the more complex jobs in the main frame system. In this sense, the complete systems may be of great long term value.

A second and perhaps more important reason to review the stand alone systems is to determine the technology on a broad base to determine what, if any, tools would be of value in the development of the ETL image processing facility. The tool search problem was primarily directed toward hardware but a brief look at the software offerings was made in the course of the review.

Corporations reviewed in the course of the stand alone device survey included: Comtal Corporation (the Series 9 system); Electromagnetic Systems Laboratory - ESL (the Interactive Digital Image Manipulation System or IDIMS); General Electric Space Division (the Image 100); International Imaging Systems - I^2S (the System 101, and the Model 500 Digital Image Processing System); Interpretation System, Inc. (a variety of devices); and Spatial Data Systems (the Data Color 703 and 704). As in the other survey elements, many other organizations are probably in the business of total image processing systems, but time and money limitations prevent a more involved review. It is also a reasonable certainty that many not currently in the business of manufacturing digital image processing systems would be interested in providing design and manufacturing if contractual arrangement could be made. These types of organizations were also omitted in the review.

Comtal Corporation

Comtal Corporation recently entered the total image processing systems market with the system they termed the Series 9. The system is apparently directed toward the LANDSAT image processing market.

The basic system parameters are summarized in Table XI.

Display System:	Comtal 8000 series
Computer System:	Digital Equipment Corporation PDP 11/35 with minimum of 24 K words of core memory
Peripheral Equipment:	
Terminal Digital Equipment CRT terminal	
Tape Units	(2 recommended)
Software System:	Comtal prepared
Special Systems:	A hardware classifier is included

Table XI

Comtal Series 9 Image Processing System

The display system is the same Comtal 8000 series described in the earlier section and is available with the standard options. The computer system is the standard DEC PDP 11/35 with 24 K words of core memory as a standard (minimum). The computer is provided with the KE 11A extended instruction set, the KE 11F floating instruction set. All data transfers to the display system are implemented using DMA to allow maximum speed of data transfer. The two tape units are recommended by Comtal for the LANDSAT image manipulation problem. The requirement for dual tape systems is not a limitation on the system in that the user may define any particular configuration desired.

The software system(s) provided by Comtal is termed "the Comtal Demonstration Software" and allows complete control of the display system (the model 8000). It also includes such items as reading images from magnetic tape, tape manipulations (positioning, etc.), cursor control, gray scale and pseudo color operations, histogram computations, interactive control of function memories, image magnification, some elementary matrix operations on an image (small segments), such as, element by element add, subtract, ratio, and multiply. A second software system is provided to allow implementation of some elementary pattern recognition algorithms. The package is termed the "Remote Sensor Interactive Training Routines" and will allow training and classification of up to four classes. The actual classification is handled by a hardware classifier.

In general the system called the Comtal Series 9 seems to be a reasonably straightforward system design which will handle a moderately sophisticated problem set including both pattern recognition and image enhancement. The cost is relatively low compared to other systems with which the Series 9 is competing. The cost was given in the range of $125,000 to $150,000.

ESL, Inc.

The ESL, Inc. activities in digital image processing hardware development have centered around a system called the "Interactive Digital Image Manipulation System" (IDIMS). The system is built around the Hewlett Packard HP 3000 computer system and is a complete stand alone system complete with operating software, display system, and associated system peripherals.

IDIMS characteristics are shown in Table XII.

Display System: Comtal 8000 Series
Computer System: HP-3000 with 64 K words memory
Peripherals:
- Disc system: 47 M word
- Terminal
- Line Printer

Software System: Based on Fortran, Basic, Cobol, and HP Languages which will allow the following processing algorithms to be implemented
- Display system control
- Gray scale manipulations
- Filtering
- Mensuration

Optional MicroProgrammable Array Processor

Table XII

ESL IDIMS System Characteristics

The ESL IDIMS system is a relatively powerful image processing system with several interesting features. Perhaps the most interesting is the multi-display system support that is provided. The computer is capable of supporting several Comtal display units from the HP3000 computer. The large number of programming languages available allow the system to be easily changed in the software sense to accommodate any new approaches to the analysis or interpretation problems. The usual or historical approaches are currently included in the software system provided with IDIMS. The software will allow operations in the Fourier or Hadamard transform plane in a reasonably efficient manner. The software system, which is developed from the JPL (Jet Propulsion Laboratory) image processing system VICAR, is well established and documented.

No information was obtained on the optional array processor, hence, any comments on the characteristics would be pure speculation. It is suggested that the interested reader contact ESL directly for any required information.

Little information was provided on the IDIMS system to the tour group. Plans for future improvements or new developments were not discussed by ESL personnel.

The only problems noted in the survey were that the system seems relatively expensive (close to $300,000) when compared to the various alternate systems. It was noted in the demonstration that the system was rather slow in response.

General Electric (Space Division)

General Electric Space Division developed a very interesting image processing system apparently directed toward the LANDSAT image user market. Many of the newer systems seen which were from other companies are in essence scaled down versions of the Image 100 system. The general Electric Image 100 Multispectral Image Analysis System (General Electric's term for the device) is a system which was designed to operate on the multi-spectral nature of objects for the ultimate purpose of recognition, that is the use of color was planned as an input to the system. One of the unique features of the Image 100 system is that it is a complete system including input image scanning (none of the other systems seen included the ability to scan an image).

The Image 100 system consists of four basic modules: an input scanner unit; an image analyzer unit; an image memory unit; and a process controller (computer and associated peripherals. Characteristics of the Image 100 are summarized in Table XIII and XIV.

Operation of the Image 100 can be started with either digital tape or an input transparency (black and white, color, or color infrared). The image is usually immediately displayed on the color CRT. In the pattern recognition mode, the operator places the cursor on the area of interest (by a joy stick control) and the system determines the spectral signature of the area. Based on the statistics, the multidimensional decision boundaries are determined and the entire image is classified. The user may repeat the process up to a total of nine times to create a thematic map of the image.

In addition to the rather elementary description of the pattern recognition operation of the Image 100, the system also has the capability for limited image enhancement, pseudo and false color assignment, and and assortment of image interpreter aids built into the software. However, the Image 100 is primarily devoted to the process of pattern recognition and as one would expect, most of the software is dedicated largely to those class of operations.

Input Scanner System:

Vidicon Scanner

525 line, 2:1 interlace, 30 frame/sec magnification up to 8:1, only 512 lines used, analog to digital conversion to 8 bits/pixel, three color filter system for sequential color scan.

Image Memory Unit

Disc Storage System

80 track disc, each track with 167K bits (will hold up to five images).

Image Analyzer Unit

Correlator for registration of images

Preprocessor for error reduction, transforms, computes correlation function, ratios

Analyzer Synthesizer for logical operations, histograms, etc.

Color CRT for display of 525 line images with cursor

Table XIII

Characteristics of the General Electric Image 100 System (Input Scanner Unit, Image Memory Unit, and Analyzer Unit)

Process Controller

Computer System Digital Equipment Corp.

PDP 11/35 with 16K words memory (can go to 32K words)

Peripheral Equipment includes:

Two Tape Units

Graphics Display Terminal

Line Printer/Plotter

Disc Unit - 1.2 M word

Table XIV

Process Control Unit for General Electric Image 100 (General Characteristics)

The software operates under the control of an executive system where the communications with the computer are mnemonically oriented (that is, user oriented). The software was primarily configured to interface with a disc operating system, but it can be "easily" adapted to magnetic tape or core memory systems.

Options to the Image 1000 are very broad, ranging from more software (such as factor analysis programs, cluster analysis programs, etc.) to extensive hardware modifications (hard copy output systems, line printers-high speed, etc.).

Costs of the Image 100 system were not available, but they are expected to be quite high (probably of the order of $500,000). The system is, in the view of the writer, the "Cadillac" of the pattern recognition/image processing systems. For the class of image processing activities to be performed at the Engineering Topographic laboratories (based on pure speculation as to what those operations are to be), the Image 1000 system does not appear to be the best match.

International Imaging Systems

International Imaging Systems Division of Stanford Technology Laboratory (I^2S) has in addition to the display system described earlier, a stand alone system product line. Specifically, two systems are available. The two systems, designated as System 101 and Model 500 Digital Image Processing System, are generically related in that the basic design philosophy is the same. The Model 500 Digital Image Processing System is actually a scaled down version of the System 101. Both systems make use of the display system described in the section of this report on Display Systems.

Each system will be described in some detail in the following paragraphs. The basic display technology of I^2S was described in the earlier section and will not be repeated here except for limitations which may be applicable to the total system. It should be noted that the Model 70 Display System was designed to be operated in the total system described here.

System 101 is the "top of the line" system from I^2S. The system characteristics are summarized in Table XV.

Display System: I^2S Model 70 User Console
Computer: Hewlett Packard 3000
Computer System Peripherals:
- Disc 4.9 M Byte
- Tape Unit (2 recommended)
- Terminal

Software: Based on HP Operating System
Application Software based on VICAR or PECOS approach to image processing.

Table XV

International Imaging Systems System 101 Characteristics

As with most other major image processing systems, only the base system can be described here. According to I^2S (as well as all other manufacturers) the final configuration of any system can be tailored to "any" user requirements.

The software system is a multiple user type which allows a high level language for command input, allows for both batch and interactive operating modes, allows for user defined macros and command lists, provides for cataloguing and maintenance of user files (such as, images, parameter, and historical files), and permits archival image storage and retrieval. The software (applications) is written in Fortran IV. The software provides for a menu prompting mode for inexperienced users. Since the system allows for both batch and interactive processing, software is provided which will permit users to program in COBOL, FORTRAN IV, BASIC, or HP.

The applications software permit the following classes of operations:

Arithmetic operations (add, subtract, ratio, divide, multiply)
Density mappings (piecewise linear, logs, exponential, histogram redistribution)
Geometric manipulations (magnify, reduce, register, warp, rotate, and scale)
Image restoration (motion blur compensation, defocus compensation, Wiener filtering, MTF compensation, homomorphic filtering, and generalized convolution)
Multispectral classification (select training sets, clustering, supervised classifier, parallel-piped classifier, Karhunen-Loève transformation, Hadamard transformation).

It should be noted that many of the operations mentioned in the above list can be accomplished in either the HP 3000 or the special purpose array processor in the User Console (Model 70).

System 101 is one of the best stand alone systems seen. A demonstration was given for the tour group and all agreed that the system was "spectacular". The only negative point raised was the response time. I^2S indicated that the "slow response time in image loading etc. was due to the multi-user environment, that is the time share. Some very minor software flaws were noted, the most objectionable was the image breakup during a function memory load operation.

System 101 costs will, of course, vary with user desired options but the overall cost for a basic system is in the range $335,000 to $545,000 depending on options.

The Model 500 Digital Image Processing system is actually a severely scaled down System 101. The display console is reduced in capability as is the computer system. The basic characteristics of the Model 500 are shown in Table XVI.

Display System: (a scaled down Model 70)
- Monitor: Conrac RHN
- Refresh System: (solid state)
  - 2 512 by 512 by 8 bit images
  - 1 512 by 512 by 2 bit graphics
- Hardware Display Processor (like the Model 70)
- Function Memories: (Input and Output) for three color planes
- Graphics Overlay Generator

Computer System: HP 21 MX with 16K Core Memory

Computer Peripherals:
- Disc: HP 7900 (5 Mbyte)
- Paper Tape Reader
- Tape Unit (7 or 9 track) one required
- CRT Terminal

Software: Designed around Hewlett Packard Disc based Real Time Executive

Table XVI
International Imaging Systems Model 500
Digital Image Processing System Characteristics

The basic system can be upgraded with as many options as other systems. It is possible to increase the refresh system up to the Model 70 capabilities (that is, up to 13 images in memory) as well as add on the other peripheral capabilities on the display system.

Software capabilities are built around the HP Real time Executive system. The general capabilities include:

Command String Interpreter
Image Entry (ERTS, Average, Line Scan)
Store Image
Miscellaneous help, listing of directories, etc.)
Display Processing including:
  Look up tables, addition, subtraction, multiplication, division
  Loading of function memories with color tables
    density remapping, contrast control, brightness control.
  Graphics (overlays)
  Min-max

The model 500 system was not seen in operation by the tour group and little comment can be made. It does seem that the system offers some small advantages in that the user can buy a complete system but it would appear that the user would prefer a little more power in the operation. It would seem that some of the Digital Equipment Corporation mini-computers would be an improvement. This comment is strictly a prejudice of the writer.

Spatial Data Systems

The final stand alone system reviewed in the survey was the Spatial Data Systems devices (termed Data Color 703 and 704). The Spatial Data Systems devices are the least expensive stand alone integrated devices. Naturally, the capabilities suffer somewhat by comparison with the more expensive systems previous described. However, if a minimum cost system is desired, the devices will perform a surprisingly large number of the operations of the more extensive systems.

A brief summary of the characteristics of the Data Color 703 system is shown in Table XVII

Display Monitor:	Conrac RHN
	Image Size: 512 by 480 pixels
	Point Intensity: 32
	Color Capability: 32 Colors
Refresh System:	Video (from a vidicon camera tube)
Computer:	Digital Equipment Corporation PDP11/05
Computer Peripherals:	RK05 Disc
	Digital Equipment Corp. Cassette
	Magnetic Tape Unit
Other Components:	Joy Stick and cursor
	Video Graphics Storage
	(Modified PEP 400)
Software Capabilities:	Magnification
	Gray Scale operations
	Limited filtering
	Laplacian
	Histograms, line profiles

Table XVII

Characteristics of the Spatial Data Systems Datacolor Devices

Characteristics of the Data Color system can best be understood from a simplified scenario. The initial image is scanned by the vidicon camera system and fed to the storage tube and analog processing station (which is included in the functional characteristics). Selected images or portions thereof may then be passed to the computer system via an analog to digital converter. The image may then be processed digitally and re-written on the storage tube for display on the color monitor. The Data-color system is perhaps more accurately a hybrid system in that both analog and digital techniques are used.

After processing,the image data is normally given over to a film recorder for permanent storage. (The film record is highly recommended by the manufacturer).

Spatial Data Systems offers a rather large array of accessories or options with the device. Many of these peripheral systems would be of interest such as the 3D display, the video micrometer, etc.

The Model 704 Datacolor is essentially the same as the model 703 described in the preceding paragraphs less some of the features (example, the 704 gives only 12 colors to the display).

As stated in the earlier paragraphs, the Datacolor system is of interest from the standpoint of cost. The system prices range from $15,000 to $50,000 for the top of the line.

Performance of the Spatial Data Systems is, of course, low relative to the other devices reviewed. The most objectional feature is the low number of colors and gray scale available. It would be assumed that the problems could be corrected if required. Other than the reduced capability, the Datacolor systems would appear to be an ideal low cost alternative.

Candidate Future Digital Image Displays

Digital Image displays which may come about in the future are strictly a matter of personal speculation. There are, however, a number of interesting devices which are in varying stages of study which could develop into the display systems of the future. This section of the survey is dedicated to the review of devices which may perform the task in the future of display of digital images.

There are several techniques one might use for attempting to forecast the future display systems. The particular one used herein is that of the technique of addressing the display screen. It was noted in the section on survey technique that display systems could be categorized by the address technique, to wit, beam addressed vs. matrix addressed. The beam addressed systems are specifically those associated with the deflected beam, in essence the CRT in a raster scan mode. The other technique, matrix addressing is essentially a discrete random access of points in the displayed image space. A few comments and potential systems are briefly examined in the following. Before starting on these "sky-blue" systems, it should be noted that most of the techniques presented herein are derived from two basic sources:

1. Proceedings of the IEEE, July, 1973
2. Assorted data and articles from the Society of Information Display

The interested reader is referred to these sources for further information.

In the beam addressed systems, the CRT system is the most popular. The systems described in this report are all CRT with raster/beam addressed technology. Enough has been said about the CRT and no further comments will be made other than the CRT system will most likely be the digital image display system of the future much as it is today.

The next beam addressed system is the scanning light beam over a screen either reflective or transmissive. Either the beam or the light path between the source of illumination and the screen may be modulated. (In the modulated light path, an optical modulator may be used on the output of the light source). In essence such systems are available (that is practical) today. The Aeronutronic Ford 3 pack system is essentially such a system even though the source is a CRT. The screen and projection system is the key element in identifying the system as a beam addressed scanning light beam system.

Candidates for new beam/matrix addressed systems lie primarily in the area of laser devices and electro-optical modulators. The need for lasers is due to the usually high power levels required to achieve minimum brightness. Typically the systems require of the order of 1 watt/square meter to achieve adequate brightness due to losses in the screen and the modulator. The technology exists to create such a display system today complete with color. The technology is just that required to write an image on film, but with refresh requirements equal to that of the CRT system. Such a system would be quite expensive and doesn't seem to offer much advantage over the CRT system. The only advantages which might occur would be: possibly high resolution, flat display screen, large screen easily achieved, and hopefully, improved geometric precision. The potential problems on the other hand include very high power requirements, possible low contrast (primarily due to screen properties, and obviously very high cost relative to the CRT systems.

Matrix addressed systems offer a great potential for the future systems for display. These matrix addressed systems can be further divided into two categories: self-illuminating and light valves. In the self-illuminated devices, one would find the arrays of light emitting diodes (LED) plasma panels and electroluminescent panels (EL panels). One other technique for the self-illuminated devices is the digitally addressed (matrix) CRT system. A few comments will be offered on each in the following paragraphs.

First consider the self-illuminated matrix addressed systems. The light emitting diode seems to be the front runner at this time. Several corporations are currently considering such a device for display of graphics data(computer terminals and cockpit displays). A survey of companies involved was not made but some of those who are currently reviewing the technology include: Hewlett Packard (Palo Alto, Ca.),and Texas Instruments (Dallas, Texas). The LED devices offer many advantages including flat screens, high brightness, geometric precision, color (would require several LED's per pixel much like the shadow mask tube), and memory (with LSI-large scale integrated-latching circuits for drivers) built in. However, a large array would be relatively expensive. In terms of prediction, the LED's are perhaps the most likely candidate for the "sky-blue" display device with matrix address capability.

Plasma display systems have been touted rather heavily for the past several years as a display candidate for graphics systems. However, the development has been lagging the anticipated time schedule. The plasma devices are classified by the writer as risky. The previous devices have been lacking a gray scale capability, with limited resolution, and low brightness. They do offer, generally, inherent memory and hence simplify the refresh problem. Some of the organizations involved in the technology include: Burroughs Corporation, Owens-Illinois, Bell Laboratories (Holmdel, N. J.), IBM (Kingston, N. Y.), Control Data Corporation (Minneapolis, Mn.), and GTE Laboratories, Inc. (Waltham, Mass.) In general, the pasma devices do not appear to be a serious candidate for future gray scale image display.

Electroluminescent (EL) panels have been considered on an off-on basis as the ultimate replacement for broadcast television system screens. The research to date has yet to produce an usable device of any quality. The EL panels do provide color, gray scale, and moderate cost potential, but do not possess memory inherently. With respect to the latter point regarding inherent memory, dielectric devices can be built into the EL panel which do allow limited charge storage, and hence could be potentially a saving in the refresh problem. High resolution is a reasonable possibility with the EL panel devices. If the research continues, then it might be expected that the EL panel could be a candidate for the future in digital image display.

The digitally addressed CRT appears on the surface to be an excellent candidate for future display systems. The only device that the writer is aware of is the "Digisplay" originally in development by Northrop Corporation and later sold to Texas Instruments. The current status of the device is unknown, however, the device was plagued by severe drive problems. The concept is highly attractive.

A summary of the self-illuminating devices is shown in Table XVIII as abstracted from the Proceedings of the IEEE, July 1973.

The light valve devices are not as well developed as the self-illuminated systems, in the overall sense. The devices are summarized in Table XIV. No other comment other than that on the Table will be made.

<u>Beam Addressed</u>	
1. Electron-Beam Addressed CRT	Not Digitally Addressed
2. Laser Beam/Optical Modulation	High Power (1 W/M^2)
<u>Matrix Addressed</u>	
1. Digisplay (Northrop - Sold to Texas Instruments)	Digitally Addressed CRT Severe Drive Problems (100 V over 300-400 pfd)
2. Plasma Panel, Self Scanning (Burroughs Corp.)	Color Available, Limited to 250 Lines, Low Peak Brightness
3. AC Plasma Panel (Owens-Illinois)	No Gray Scale, Expensive (?)Red Display, inherent memory
4. Electroluminescent Panel	Various Color, Gray Scale, No Memory, Risky Development
5. LED	Bright, Colors Available, Flat Panel, Expensive

Table XVIII

Summary of Exotic Display Techniques
(Self Illuminating)
Ref. Proc. IEEE, July 1973

Light Valves, Beam Addressed	
1. Titus Tube (KDP Crystal) (Philips)	Very Experimental
2. Cathodochromic Dark Trace Tube	Slow Scan, High Resolution
3. Oil Film Diffractive	Has Performed Real Time TV, Reliability a Problem, Bulky.
4. Laser Addressed, Nonerase	Uses Film Type System, Not Erasable
5. Photoconductor Approach (Band Gap Shift, Reflectance Change).	High Resolution, Memory, Uniform, Slow, Bulky

Light Valves, Matrix Addressed	
1. Electrochromic (thin films)	Memory, Good Contrast
2. Colloidal Dipole Suspension	Uniform Reliability Problems, Limited Temp. Range
3. Electrophoretic Suspension	

Table XIV

Summary of Exotic Display Devices

(Light Valves)

(Ref. Proc. IEEE, July 1973)

In summary, there appears to be no immediate new technology on the horizon which will replace the CRT as the primary interactive digital image display. However, the developments in LED and EL panel technology should be carefully monitored as both appear to offer some very long term potential.

Conclusions and Recommendations

Results of the survey on digital image display systems were not particularly surprising in that most of the new developments seen were predicted by many who have followed the developing field. The new elements observed in the course of the survey include the application of solid state memory for refresh of the monitor in almost all manufacturers of display systems, and the appearance of a new "1000" line monitor from two suppliers. The solid state memory is being used by Comtal, International Imaging Systems, and Ramtek in the new monitors/display systems. In fact, no display systems are currently manufactured which use disc refresh for the monitor system.

Despite the application of solid state refresh memory in most of the current systems, there still exists problems in the refresh system. The cost is still nigh for the RAM and shift register technology being used. The ultimate refresh system will most likely be found in CCD technology. The current techniques are too slow for the potential application to "large" display monitors (that is monitors of the future which may require up to 2000 x 2000 elements). The cost factors are simply that the refresh system still dominates the cost of the entire display system. It is believed that the cost factor will of course decrease with time, probably with the eventual use of CCD technology.

In the area of monitor technology there still exists numerous problems. All current monitors used in the display of digital images are identical to those used for broadcast television. In fact all the monitors manufactured by Conrac are used primarily as broadcast standards by the various studio organizations. For the application that they were designed, the monitors are excellent. However, the requirements for the digital image processing community are radically different. As an example, the broadcast monitors are designed with a curved faceplate to allow off axis viewing (to support multiple viewers). In the digital image processing problem there is usually only one viewer, the analyst. The curved faceplate does introduce distortions which are deleterious to accurate mensuration and are complicated to remove pre-display. The tubes (CRTs) are also designed to require the minimum depth for home use by means of wide deflection tubes. The wide deflection (of the order of 110°) causes another class of distortion which interferes with the interpretation of the image being displayed.

The areas where improvements appear warranted in the monitor technology include:

Increased resolution (up to 2000 by 2000 full color)

Flat faceplates

Simplified convergence techniques

Improved Linearity (of the order of 0.005%)

Special tube sizes and geometry

In each of the areas, the technology is available to permit achievement of a set of reasonable design objectives. It is unlikely that improvements will occur, however, without direct government funding. The monitor manufacturers are unlikely to address the problems of digital image processing community as there is a very small market involved (relative to the commercial world).

Lack of a set of reasonable specifications for display systems is a major problem in the device technology. Many of the needs of the processing and display of digital images are not understood by the various manufacturers, and as a result the devices which are being marketed are the product of the vivid imagination of the engineers involved. It would not be expected that all facilities would have the same requirements, but the differences would not obviate the application of a general set of guidelines. At a minimum the various organizations concerned with the display of digital images should prepare a set of operational scenarios as a guide to both manufacturers and users, in essence, to inform the manufacturer of the use to which his device will be subjected. A requirements study should be undertaken for the individual user.

Of the display devices reviewed during the tour, the International Imaging Systems Console 70 appeared to be the closest match between the assumed requirements for the ETL facility and the device capability. It is understood that there is a potential difficulty in procurements with I^2S due to the foreign ownership of the company. The Comtal 8000 series is very high on the recommended list and in many instances are to be preferred to the I^2S system. The primary reason for the preference is the interface question. The Comtal device has been interfaced to many different computer systems while the I^2S system has not. Regardless of system procured, it is recommended that the new 1000 line monitor be included in the procurement.

No recommendations on the stand alone devices are made herein as they are not required for the ETL system.

APPENDIX

NAMES AND ADDRESSES OF ORGANIZATIONS PARTICIPATING IN THE SURVEY OF SOFT COPY DEVICES

This appendix is a detailed listing of organizations contacted and reviewed during the survey of soft copy display devices. Addresses and phone numbers along with principal contacts are also given as an aid to those readers seeking more detailed information.

1. Aeronutronic Ford Corporation
   Western Development Labs
   3939 Fabian Way
   Palo Alto, CA 94304
   Phone: 415/ 494-7400
   Principal Contact: R. Workman

2. Comtal Corporation
   169 Halstead
   Pasadena, CA 91107
   Phone: 213/ 588-3256
   Principal Contact: Mr. John Tahl

3. Conrac Corporation
   Conrac Division
   600 N. Rimsdale Ave.
   Covina, CA 91722
   Phone: 213/ 966-3511
   Principal Contact: Mr. Wm. Ems

4. ESL Incorporated
   495 Java Drive
   Sunnyvale, CA 94086
   Phone: 408/ 734-2244
   Principal Contact: Mr. James Burke

5. Hughes Aircraft Company
   Culver City, CA. 90230
   Phone: 213/ 391-0711
   Principal Contact: Mr. Louis Seeberger

6. International Imaging Systems
   Division of Stanford Research Laboratory
   510 Logan Ave.
   Mountain View, CA 94043
   Phone: 415/ 969-2700
   Principal Contact: Mr. Michael Battaglia

7. Ramtek Corporation
   292 Commercial St.
   Sunnyvale, CA 94086
   Phone: 408/ 735-8400
   Principal Contact: Mr. Charles Norby

8. Sierra Scientific Corporation
2189 Leghorn Street
Mountain View, CA 94043
Phone: 415/ 969-9315
Principal Contact: Mr. David Gilblom

9. Spatial Data Systems
508 South Fairview Avenue
Goleta, CA 93017
Phone: 805/ 967-2383
Principal Contact: D. Rutland

10. Dicomed Corporation
9700 Newton Ave. South
Minneapolis, MN 55431
Phone: 612/ 888-1900
Principal Contact: Mr. Wayne Hochstedler

11. General Electric Company
Ground Systems Department
Space Division
P.O. Box 2500
Daytona Beach, FL 32015
Phone: 904/ 258-2635
Principal Contact: R. W. Towles

12. Interpretation Systems Incorporated
P. O. Box 1007
Lawrence, KS 66044
Phone: 913/ 842-5678
Principal Contact: None

13. Princeton Electronic Products
P.O. Box 101
North Brunswick, NJ 08902
Phone: 201/ 297-4448
Principal Contact: None

14. Litton, Industries
4500 Campus Drive, Room 116
Newport Beach, CA 92664
Phone: 714/ 546-3338
Principal Contact: None