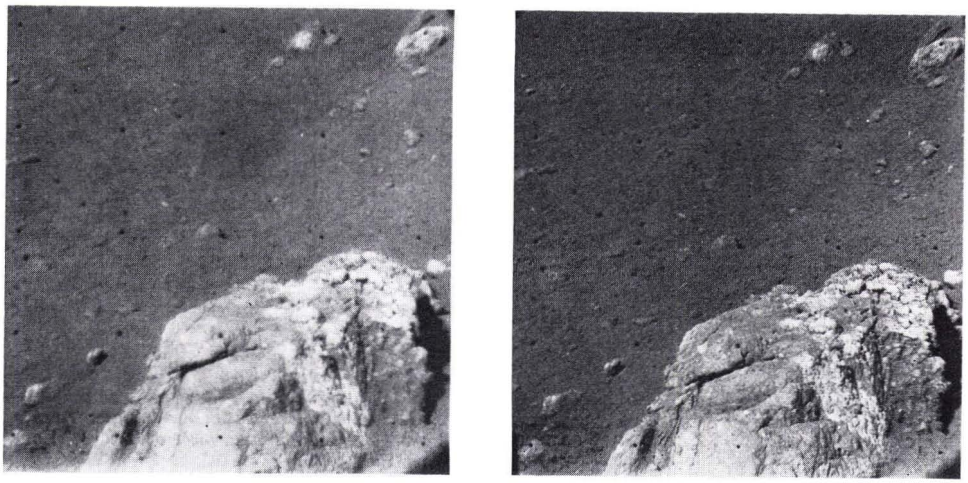

FRONTISPIECE. Lunar surface as taken by Surveyor I. The view on the left is *Before Enhancement*, and on the right is *After Enhancement*.

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Image Processing by Digital Systems

The resultant pictures will be displayed with clarity and detail that could not normally be seen.

INTRODUCTION

THE PURPOSE OF this paper is to describe a technique by which television pictures can be stored, processed and pictorially displayed by use of a digital computer system. The system described, which will be referred to as the Image Processing System (IPS), will aid the photointerpreter (user) in the diagnosis of an image in an on-line, multiprogramming, man-computer conversational and time-sharing mode.

The IPS will automatically read pictorial information that may be present on an analog tape (similar to a video tape), or in normal photographic form. It will then digitize the image, extract significant information, mathematically manipulate it, compare it with previously stored data and available knowledge, and pictorially display on a cathode ray tube (CRT) the information that the photointerpreter desires to view. The photointerpreter will be able to communicate with the system via a light pen, a keyboard, and a typewriter to ask questions and make requests. The previously stored computer programs may remove digitally the noise created during the television and transmission processes, and can apply various digital filters to return the received signals to their original strength (enhancement of the pictures). The programs can also correct for other television imperfections which cause geometric distortion and intensity errors. The resultant pictures will be displayed with clarity and detail that could not normally be seen. At the request of the photointerpreter, in an on-line, man-computer conversational mode, additional picture processing can be performed

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such as enlargement of sections, as well as contour map generation and pattern recognition to locate and perform measurements on various picture features.

The multiprogramming mode and time-sharing capability consist of a background and multi-user mode, respectively. The background mode will permit the normal production job to be processed while the user is at the console thinking about his next operation and not using the computer. When the user is ready for his request, the production run will be interrupted and saved, and control will be returned to the user with the conditions that existed previously. The multi-user mode will permit many terminals to be communicating with the system under normal time-sharing concepts.

A system similar to that described is presently being assembled at Jet Propulsion Laboratory, Pasadena, California, with the programming support of IBM/Federal Systems Division. At JPL, the system will be used to process digitally television pictures of space bodies which were transmitted from unmanned space vehicles. It will also be used for digital enhancement and processing of medical images, such as x-ray photographs, in determining tumors and other physical anomalies.

The system described assumes an interactive CRT display console (television) and a time-sharing programming system. However, the IPS as presently specified by JPL does not contain these capabilities.

The next three sections detail each element of the IPS and describe various applications of the system. The fourth section of this paper contains pictures that exemplify the output of the system. These pictures were prepared under the JPL system using an IBM 360/44 computer.

Image Processing System

This section describes the various components of the Image Processing System. The system basically consists of two parts, the hardware and the software. The following subsections will handle each separately.

HARDWARE

The IPS consists of an IBM 360/44 computer, a Video Tape Converter (VTC), a Video Film Converter (VFC), and a Video Data Console (VDC).

The VTC is the device designed to convert analog signals to digital form for use by the digital computer. As they are received from the spacecraft, the analog signals are originally stored on a magnetic tape that resembles a video tape. By use of the VTC, the analog tape can be converted to a string of digital quantities, and the digital information can either be sent directly into the digital computer system in real time, or stored on a digital magnetic tape for processing at a later date. The VTC can convert the analog data in 6-bit or 8-bit quantities that represent the gray scale value at each particular television picture point.

The VFC is the device that converts the

ABSTRACT: *A technique by which television pictures can be stored, processed, and pictorially displayed by use of a digital computer system is designed to aid the photointerpreter (user) in diagnosing an image in an on-line, multiprogramming, man-computer conversational and time-sharing mode. The photointerpreter will be able to communicate with the system via a light pen, a keyboard, and a typewriter to ask questions and make requests. In addition, the stored computer programs may enhance the image to a superior level of clarity and detail. The paper details the Image Processing System as well as the numerous space and medical applications.*

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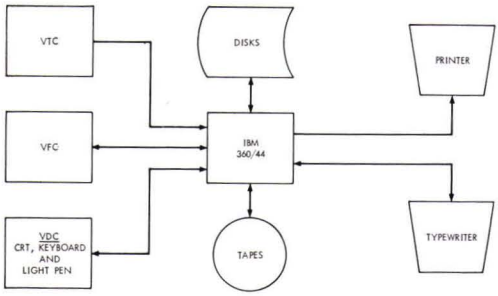

FIG. 1. IPS block diagram.

digital data output from the digital computer to analog form to generate the hard-copy picture. The VFC can read the digital quantities directly from the digital computer system or from a digital magnetic tape. Subsequently, it converts the signals to analog form to generate the picture line by line on a cathode ray tube which is automatically photographed under a time exposure technique. The result is a 35 or 70-mm film from which hard-copy prints can be made. The VFC also has the capabilities to scan a 35 or 70-mm negative and create digital signals which can be fed into the computer or stored on tape. This feature enables the digital processing of pictures that are originally in hard-copy form such as chest x-ray photographs previously taken.

The VDC contains an interactive CRT (television) display which may operate in color or in black and white, and permits the user to view the complete image immediately after the digital computer generated it. Since a display such as the VDC would be a useful addition to the IPS, this paper assumes its availability along with its required software.

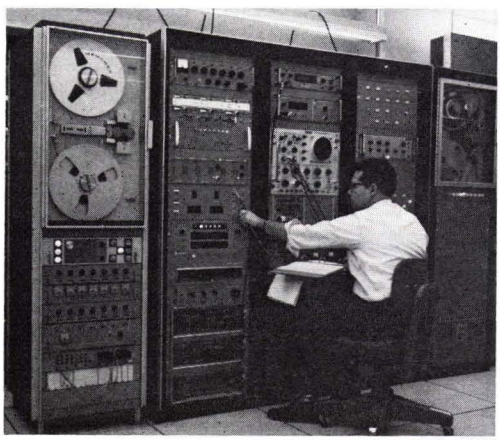

FIG. 2. Video tape converter.

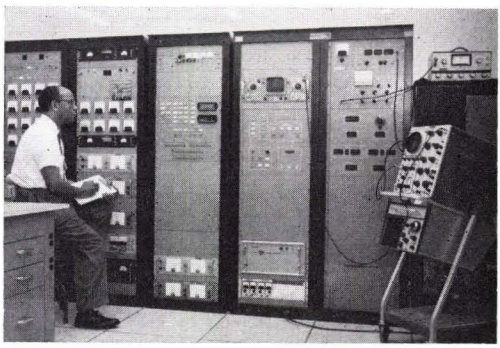

FIG. 3. Video film converter.

The VDC display is controlled by the digital computer software and permits the user to communicate with the digital system by means of questions and requests via a light pen and keyboard. The VDC with the related controlling software permits the photointerpreter (user) to manipulate digitally the television picture in an on-line, man-computer conversational fashion.

The digital computer is an IBM 360/44 which utilizes tapes, disks, a printer, and a typewriter, and will be the master controller manipulating all pictures and other data and hardware, as desired. It will contain a master system program (refer to the following subparagraph entitled *Software*) which will permit the user to call on all hardware and digital computer programs by use of a specialized picture processing language that may be easily learned and used by individuals untrained in programming.

Figure 1 shows a simplified block diagram of the above mentioned hardware units and their interrelationships.

Figures 2 through 4 show the VTC, the VFC, and the IBM 360/44 computer as they are installed at JPL, Pasadena, California. The VTC

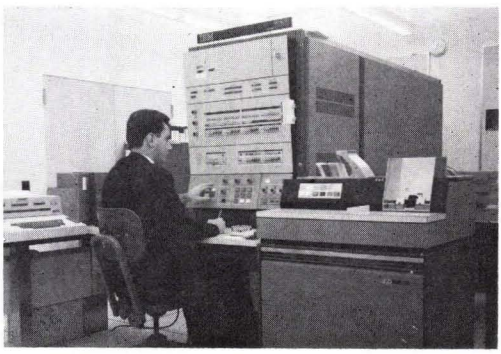

FIG. 4. IBM 360/44 computer.

was designed and built by JPL. The VFC was built by Link/General Precision Corporation under JPL's specifications.

These photographs were taken by JPL and presented to IBM for use in this paper.

SOFTWARE

The software package operates under the 360/44 computer and consists of two program sets, the system programs and the functional programs. The following paragraphs describe each set individually.

System. The system programs are written to permit the programmer and user to manipulate easily pictures and other data, as well as hardware, by omitting the user performance of normally complex I/O and other complex computer programming tasks. Two sets of specialized language systems were designed, a problem programmer's language and a user's language.

The problem programmer's language was designed for use by the programmer who wishes to write additional picture manipulation routines (refer to the following subparagraph entitled "Functions"). This language or system consists of a group of subroutines that may be called by the programmer to handle all his complex television picture I/O and all his input data transfers. This option relieves the programmer of all I/O operations so that he can concentrate on the mathematical or internal data manipulation procedures; these may be written either in Fortran or in assembly language.

The user's language was written to permit the user or the individual untrained in programming to manipulate television pictures, other data, and hardware through a simplified language incorporating English words, without performing complex programming procedures. This set of system programs translates the designed user language to meaningful computer code and oversees the proper execution of the code. The user language was designed with sufficient flexibility to allow the user to execute several pre-written picture processing routines (functions) on many different pictures in a few simple statements.

Functions. The functional programs (functions) are the actual picture processing routines used by the system. These are the digital programs that remove noise from a picture, correct for lens geometric distortion and camera intensity errors, apply digital filters to enhance the pictures, compare previously taken chest x-ray photographs with the present ones to detect changes, etc.

Large numbers of simple and complex functions may be written for image processing under the system. For example, a function to subdivide a picture into many smaller pictures is comparatively simple, whereas a function to generate digitally a contour map from a surface photograph, or a function to perform involved pattern recognition are quite complex.

APPLICATIONS

There are many different types of applications for a system such as the IPS. In this report, however, only the space and medical applications which are of concern to JPL will be discussed. Some of the following applications require a display (such as the VDC) and a time-sharing software system.

The IPS will permit the space scientist to request a CRT display of a particular picture showing the surface of a space body as taken from a space vehicle. He will then have the ability to request that the system remove from the picture all inaccuracies caused by the camera lens (geometric distortion), by the finite size of the camera scan beam, by the nonuniform vidicon brightness response of the television camera, or by any other television or transmission system noise.* He will then obtain a much clearer, sharper, and accurate picture and be able to make decisions about the characteristics of the surface. He can then request by use of his light pen, keyboard, typewriter, or cards, different projections (views), enlargements, or even contour maps of the specific areas of interest. After performing various picture manipulations, he can request any desired number of hard copies for subsequent analysis.

It should also be remembered that the picture processing described above occurs in an on-line, man-computer conversational mode, and that many terminals and production jobs can also be functioning.

The medical applications of IPS are also quite numerous. The IPS can aid the physician in diagnosing his patient's ailment in the same efficient and flexible manner described above by communicating with the system via a light pen, a keyboard, and a typewriter to ask questions and make requests.

The system will be capable of automatically reading pictorial medical data such as x-ray photographs, extracting significant information, comparing it with previously stored data and available knowledge, and pictorially displaying on a CRT (television scope) the

* For details on digital correction techniques, see Reference 1.

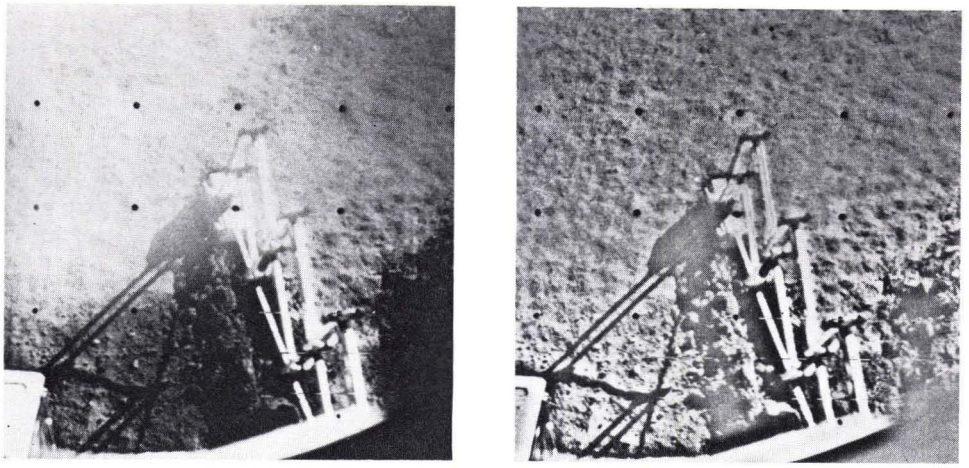

FIG. 5. Arm of Surveyor III extracting sample of lunar soil. The view on the left is *Before Glare Filter*, and the one on the right is *After Glare Filter*.

specific information that the physician requests. This philosophy was successfully attempted by JPL to detect chest tumors through computer comparison of two *x*-rays taken at different times (Reference 2).

With the IPS, the computer possesses the capability to detect the true signals concealed by the noise created by the *x*-ray photographic process, and to display the *x*-ray picture on a CRT at a level of clarity and detail that could not normally be obtained. In addition, the system could enlarge, manipulate, or further enhance any particular area specified by the physician for his diagnosis, and/or possibly in the future, could use the computer as a specialist recommending the appropriate treatment to the physician. The system could diagnose the case by using the patient's past history and other similar case data, as well as by referring to stored knowledge generated by experts in that particular field of medicine. The computer could perform various pattern recognition operations to locate features, and then perform measurements to determine the condition, such as the measurements required to determine an enlarged heart. Therefore, with such a system, a single physician could diagnose a case in a very short period of time and without fatigue, and obtain the same, if not better, results than could be achieved by a large group of specialists applying present techniques.

ILLUSTRATIONS

This section refers to the photographs that illustrate the level of improvement obtainable by use of the Image Processing System. The following sets of pictures were prepared at JPL under their IPS.

The Frontispiece on page 1058 shows the lunar surface as taken by the Surveyor I spacecraft. The picture entitled *Before Enhancement* was digitized, assembled on the IBM 360/44 computer, and played back on the VFC to produce the hard copy. The picture entitled *After Enhancement* underwent the same process, except that a digital sine wave response filter was applied by a function program to emphasize the high-frequency signals to restore their original strength. This process is used to compensate for the attenuation of the higher frequencies caused by the finite size of the camera scan beam. The resultant picture shows the marked improvement in sharpness and clarity.

Figure 5 shows the arm of Surveyor III extracting a sample of the lunar soil. The picture entitled *Before Glare Filter* underwent the same process as the picture entitled *Before Enhancement* in the Frontispiece. The second photograph entitled *After Glare Filter* also underwent the same process as the first picture of this set, except that a digital filter was applied to remove the sun's glare, which is readily noticeable in the *Before Glare Filter* photograph.

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