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KNOWLEDGE-BASED IMAGING-SENSOR FUSION SYSTEM†

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INTRODUCTION

This paper describes an imaging system which applies knowledge-based technology to supervise and control both sensor hardware and computation in the imaging system. It includes the development of an imaging system breadboard which brings together into one system work that we and others have pursued for LaRC for several years. (Refs 1,2,3). The goal is to combine Digital Signal Processing (DSP) with Knowledge-Based Processing and also include Neural Net processing.

The system is considered a smart camera. Imagine that there is a microgravity experiment on-board Space Station Freedom with a high frame rate, high resolution camera. All the data cannot possibly be acquired from a laboratory on Earth. In fact, only a small fraction of the data will be received. Again, imagine being responsible for some experiments on Mars with the Mars Rover: the data rate is a few kilobits per second for data from several sensors and instruments. Would it not be preferable to have a smart system which would have some human knowledge and yet follow some instructions and attempt to make the best use of the limited bandwidth for transmission?

This paper will describe the system concept, current status of the breadboard system and some recent experiments at the Mars-like Amboy Lava Fields in California.

SYSTEM OVERVIEW

The system architecture concept is shown in Figure 1. The four areas shown are sensors, focal plane processor, knowledge-based supervisor/controller and image processors. Inputs to the system are supervisory commands, channel capacity and other mission data. The output is edited, classified and coded data, as well as other feature and range information.

Internal communications are provided so that sensors and processing can be supervised and controlled by the knowledge-based system. Rules, knowledge, data and researcher's expertise are contained in the Knowledge-Based Supervisor/Controller KBSC.

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The data from multiple sensors are simultaneously processed and combined by the KBSC.

Signal and image processing will be performed both in the focal plane processor and with the image processor.

The parallel asynchronous processor and the KBSC and image processing hardware are described in other papers (Refs. 2, 3). The laser ranger system and goals of the KBSC system will be discussed here.

Figure 2 is a different view of the knowledge-based image/sensor fusion breadboard in that it segments the knowledge-based and signal processing in the manner in which it is implemented in the breadboard system. The knowledge base is hosted on a SUN computer and the real-time signal/video processing is on the Datacube pipeline image processor. The sensors are CCD cameras, IR sensors and laser ranger.

INTEGRATED LASER CAMERA

The integrated laser camera combines range data from the laser with the spatial reflectance data from the CCD camera. The concept is to provide a sensor which has both high spatial resolution and accurate range to specific objects in the scene. Table 1 summarizes the limitations of either sensor separately and the potential of fusing the data from each to give both range and spatial detail.

Table 2 lists the function of the ILC. The range may be provided at a single point or a range image may be generated by scanning the ranger over an area. Several display functions are available such as a contour map and an artificial grid to provide the concept of depth and range to any object in the scene. Camera control functions such as focus and zoom can be performed from the range output. Combining the range with high frequency spatial data can achieve rapid and very reliable camera focus.

Combining range and spatial data has many applications in image analysis, such as segmentation, distinguishing objects from shadows, obstacle avoidance, etc.

LASER RANGER

There are basically two types of lasers, pulse and continuous wave. Pulse laser rangers operate on the basis of measuring the time it takes a laser pulse to travel to the object and back to the receiver. A continuous wave (CW) laser ranger normally compares the phase shift between the transmitted and received wave. A discussion of the merits of CW vs. pulse is beyond the scope of this paper except to say that pulse laser rangers require less computation for range and generally are better for long-range imaging, for example, beyond 200 meters. Range ambiguity also needs to be resolved when using a CW laser ranger.

We selected a pulse laser shown in Figure 3 with the specifications shown in Table 3. Range, accuracy and firing rate were all important in selecting the laser ranger. The 2000 firings per second makes it quite feasible to generate small range images. An accuracy of about 5cm to 10cm can be achieved by averaging over a number of firings on a single object.

Figure 4 shows the block diagram implementation of the integrated laser/CCD prototype system. The laser ranger is mounted on a precision pan/tilt platform. The platform is controlled by the SUN either to point to a specific object or to scan an area to generate a range image. The camera focus and zoom will be controlled by the laser ranger in the breadboard imaging system. The video rate Datacube processor generates a graphics overlay on the video image such as the laser beam location.

Figure 5 shows the platform design for the ILC. The azimuth motion is provided with a rotary stage platform on which is mounted a goniometer for the elevation motion. The platform has a repeatability of about 0.17mR about each axis. The laser ranger will be bore sighted with the camera axis.

KNOWLEDGE-BASED SUPERVISOR/CONTROLLER

The objective of the KBSC is to provide a robust, flexible monitoring and control system which provides sensor control, processing and image coding control, outputs edited, classified and coded data based on an internal knowledge-base and data base, sensor input, and supervisory command.

Figure 6 shows some of the input, outputs and control functions of the KBSC system. The inputs to the KBSC can be from image processors such as the spatial frequency, histogram or other computed characteristics of the image. It may be a previously identified object or area so as to designate a small region of interest (ROI). Edge information and segmentation may be used to identify specific features in the image. The color or more generally the spectral response of the image may be used to identify regions or objects.

From the laser ranger, range and reflectance data may be used with the spatial data to identify features. Laser reflectance values may be used to determine the reliability of the range data and to determine the reflectance of the target at the laser frequency. The field of view (FOV) may be important when selecting processing algorithms. Sun angle, available bandwidth, and other priorities will be used to select processing algorithms and image coding methods.

In addition to sensor control such as focus, the KBSC will also be useful in applying the user's knowledge to select the information and data which is important.

AMBOY DATA COLLECTION

Some of the features of the breadboard imaging system are implemented in the Odetics Mobile Imaging Laboratory. Figures 7, 8, and 9 show the Mobile Imaging Laboratory platform with infrared and CCD cameras and platform with the laser ranger. Figures 10 thru 16 are samples of a set of images taken with the Mobile Imaging Lab at the Amboy Lava Field in the Mohave Desert which looks very much like Viking pictures of Mars. Figures 10 and 11 are CCD and laser scan images respectively of approximately the same area. Some of the very black lava in the lower right band corner did not reflect enough signal for the range computation. The bush in the center of the scene is clearly visible. (The black and white print was made from a pseudo color range image (Figure 11), causing the ranges at 50-60 meters to appear closer.)

Figures 12 and 13 are photographs of Amboy terrain which looks remarkably like the Mars Viking pictures except for a few bushes.

Figures 14 and 15 are infrared images (8-12μm) of the Amboy crater taken when the temperature was about 110°F. The white areas in the IR image are hot.

Figure 16 shows a panoramic scene of the Amboy Lava Field taken with a series of images with a narrow field-of-view camera on the pan/tilt platform. Figure 17 is an artist conception of how a Mars Rover camera might assemble narrow field-of-view pictures into a panorama. The image was digitized from an actual Mars Viking photograph.

REFERENCES

1. Tom N. Cornsweet, "Image Processing by Intensity-Dependent Spread (IDS)", International Workshop on Visual Information Processing for Television and Telerobotics, NAS CP-3053,1989. (Page 133 of this compilation).

2. D.D. Coon and A.G.U. Perera, "Parallel Asynchronous Systems and Image Processing Algorithms", International Workshop on Visual Information Processing for Television and Telerobotics, NAS CP-3053 1989. (Page 191 of this compilation).

3. E.R. Kurrasch, "Applications of the IDS Model", International Workshop on Visual Information Processing for Television and Telerobotics, NAS CP-3053 1989. (Page 165 of this compilation).

TABLE 1

INTEGRATED LASER RANGER/CAMERA SYSTEM

Problem:

Existing robot vision systems do not provide both range and high resolution.

■ Extracting range from the image data of CCD cameras is extremely computer intensive and provides poor 3-D contour data.

■ Laser ranging/scanning systems provide range and 3-D contour data, but image detail is poor.

Solution:

Provide intelligent fusion of high resolution CCD camera data and laser ranging data.

Use an expert system for determining how the data from different sources will be used to extract scene data.

TABLE 2

ILC FUNCTIONS

- Range to any point in scene
- Range image of any area in scene
- Display (range image, contour map)
- Display depth grid
- Display range to any point
- Focus camera
- Combine range and reflectance data

TABLE 3

501 LASER RANGER SPECIFICATIONS

Range	10-500 m
Accuracy	.2m
Resolution	.1m
Beam divergence	2.5 mR
Measurement rate	1–2000/sec
Weight	3 Kg
Power	3A @ 12V

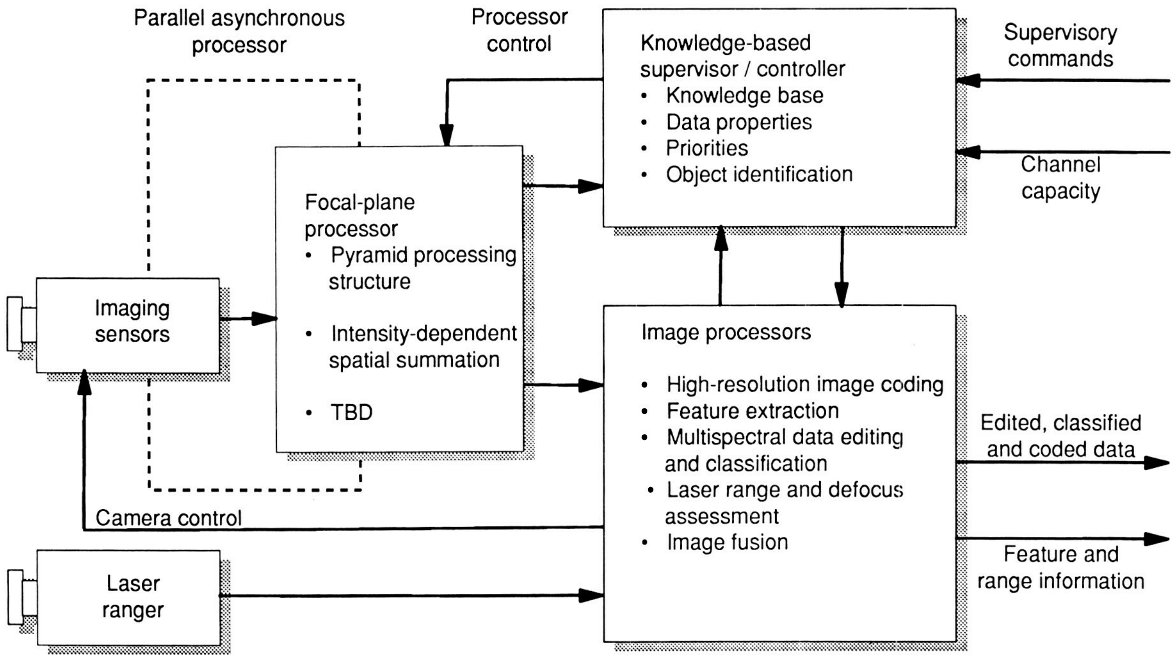

Figure 1 Knowledge-Based Image/Sensor Fusion System

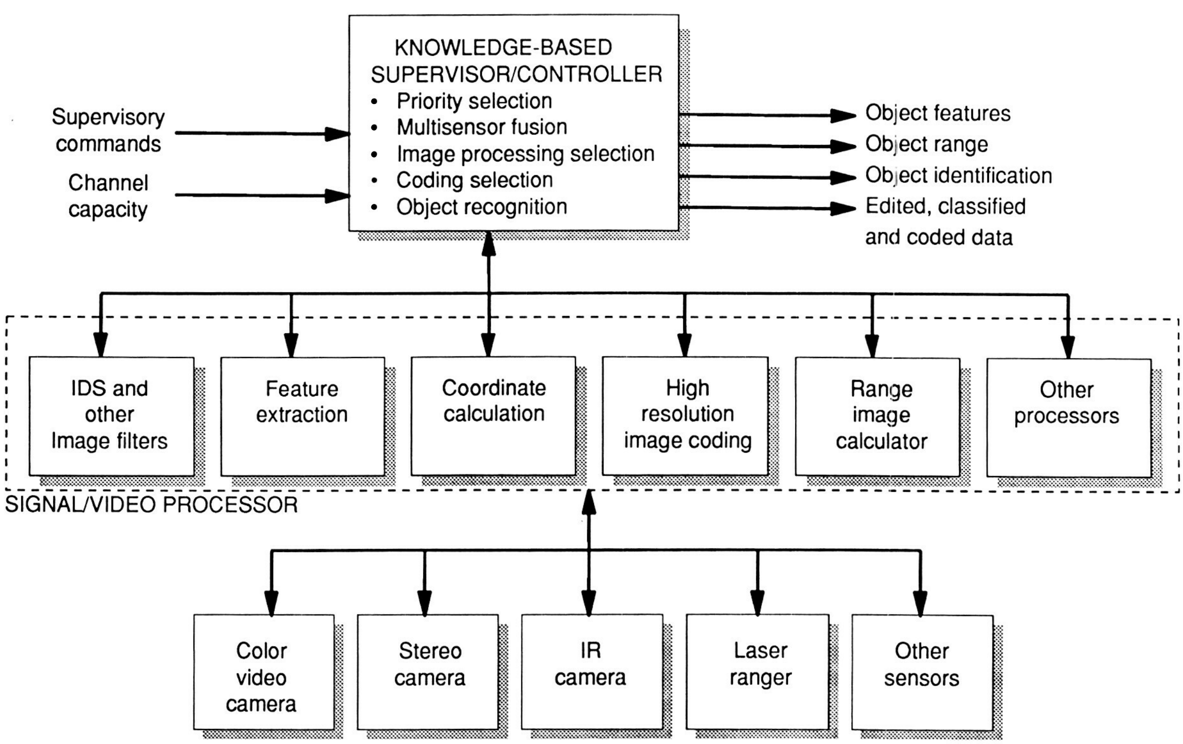

Figure 2 Knowledge-Based Imaging/Sensor Fusion System

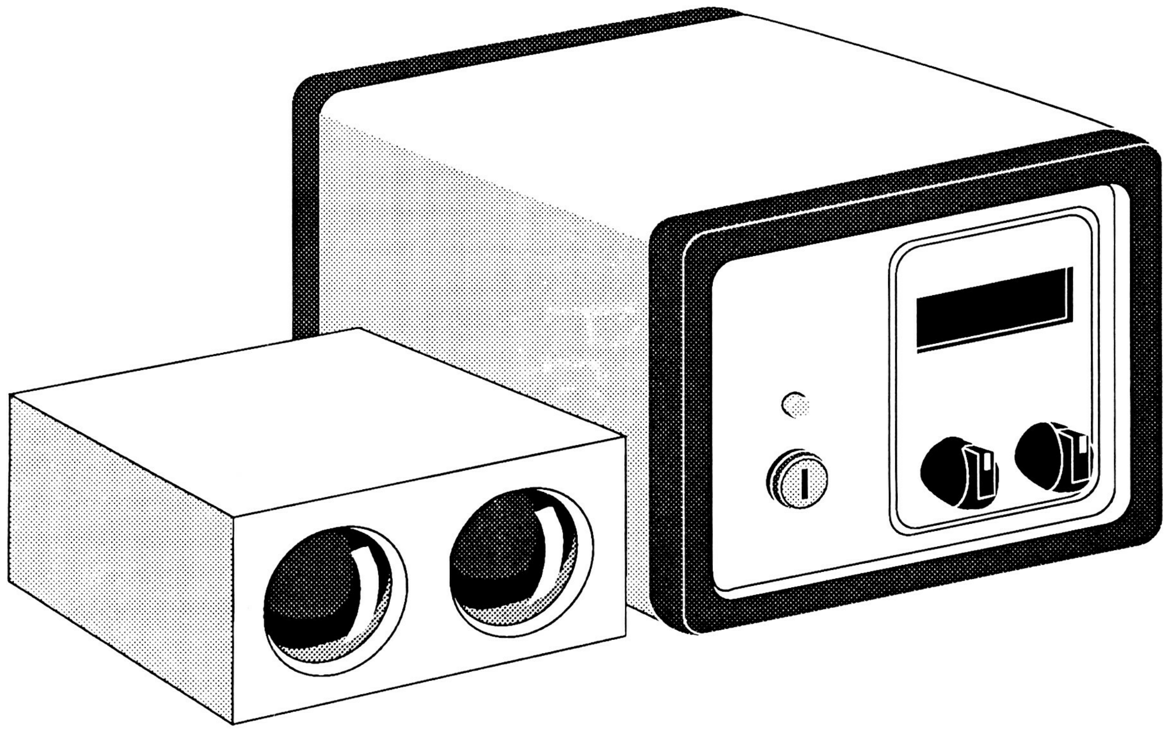

Figure 3 Rangefinder 501/SX

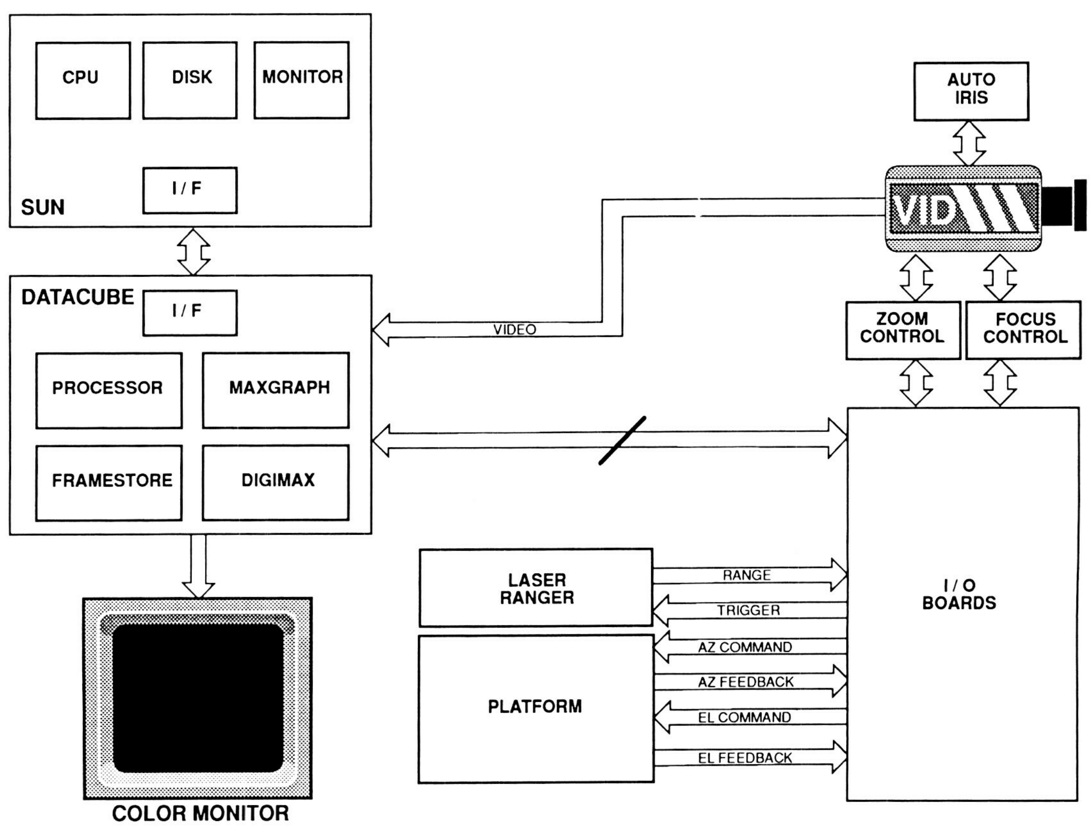

Figure 4 ILC System Block Diagram

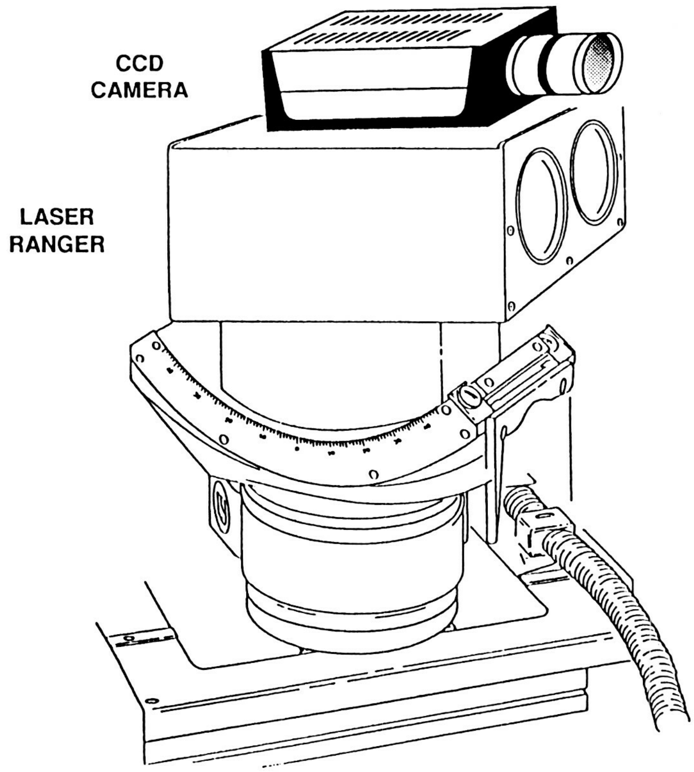

Figure 5 Platform Design for the ILC

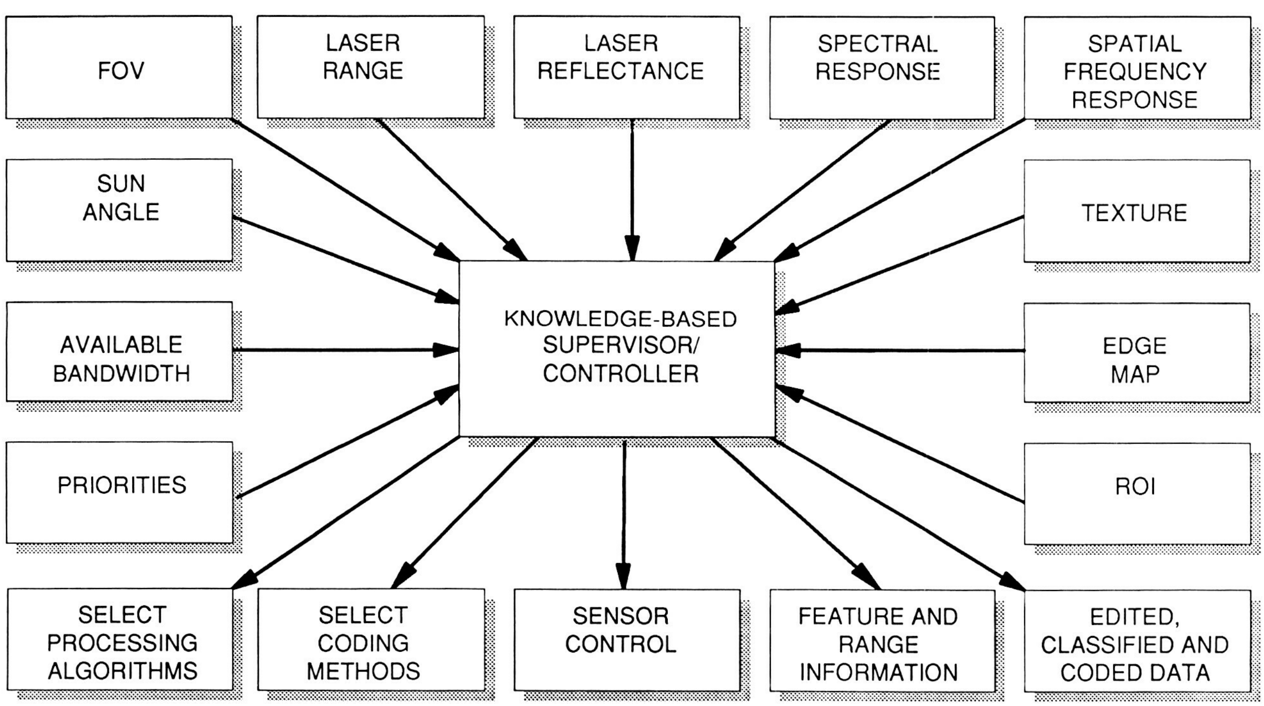

Figure 6 Knowledge-Based Supervisor/Controller

Figure 7 Odetics Mobile Imaging Laboratory

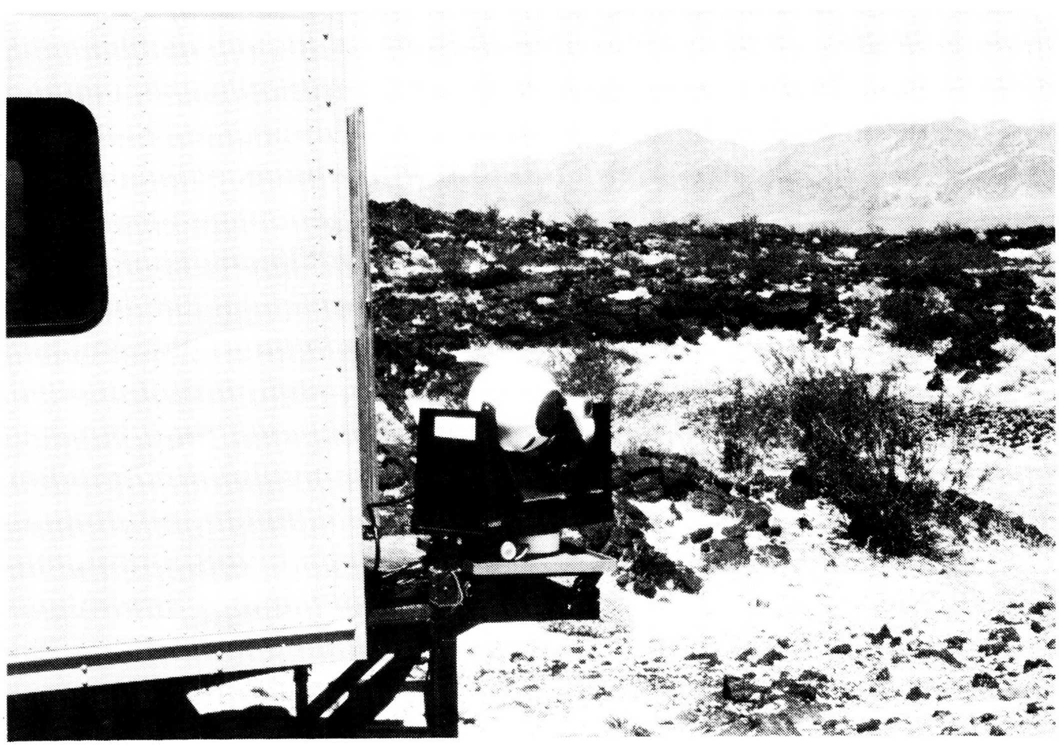

Figure 8 Sensor Platform with Infrared Camera

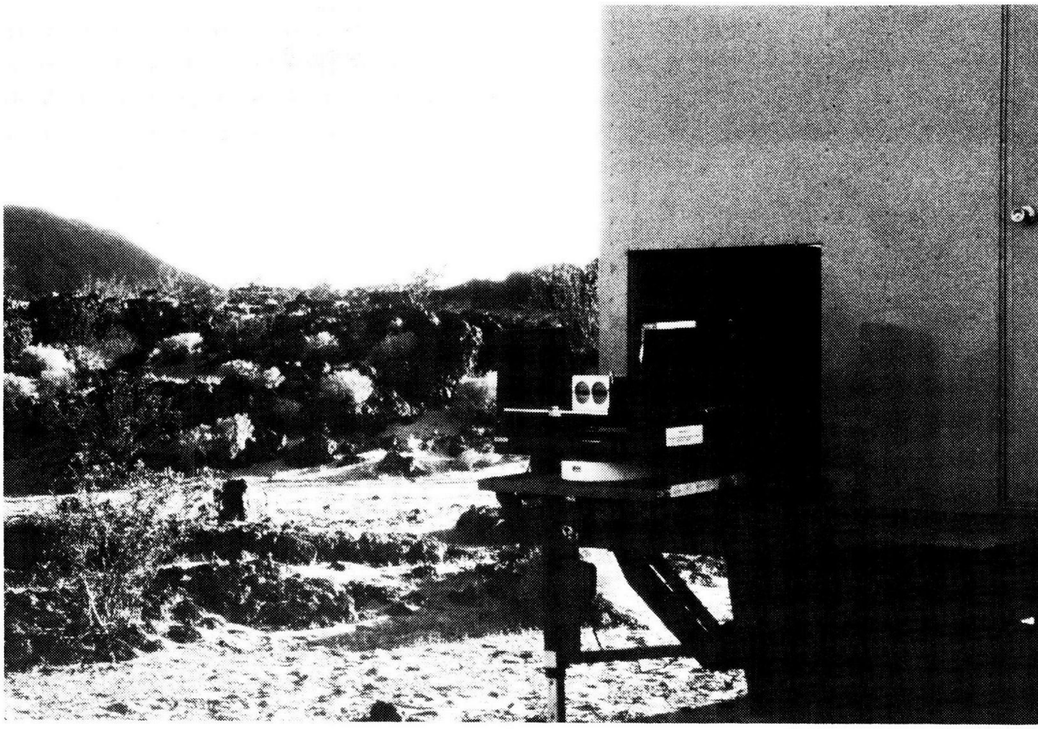

Figure 9 Sensor Platform with Laser Ranger

Figure 10 CCD Image Amboy Lava Field

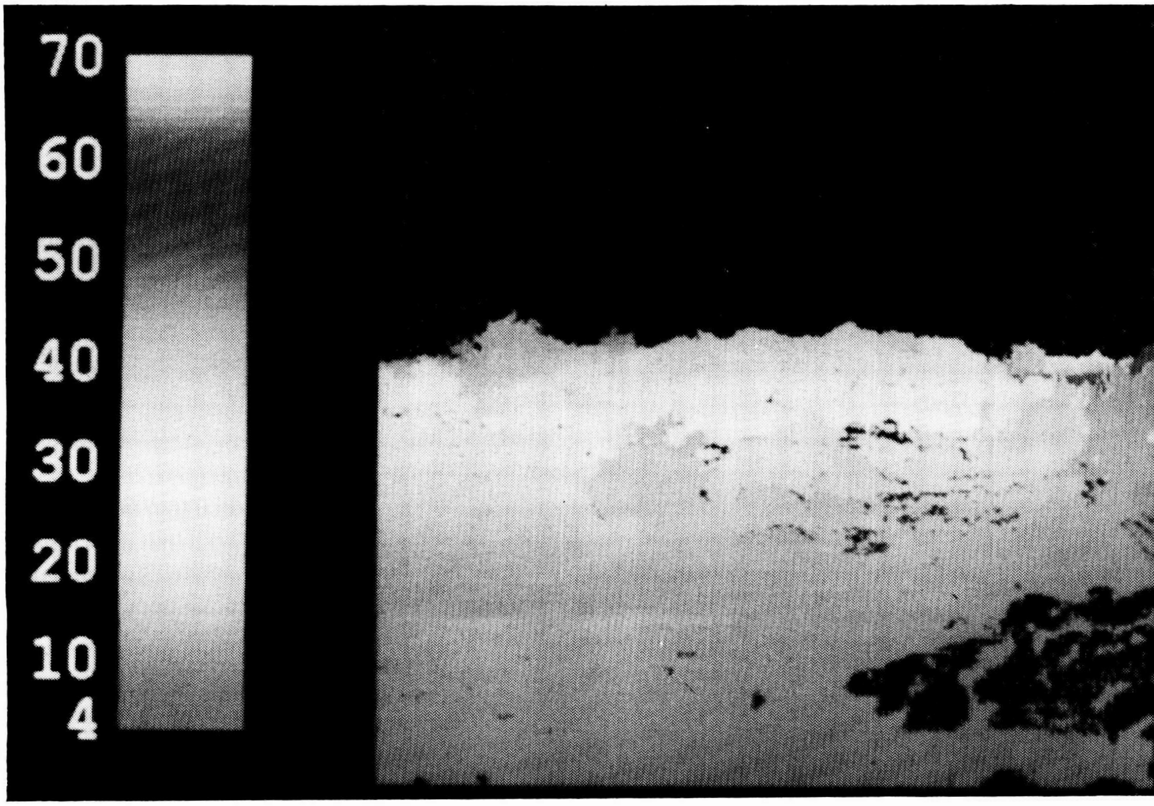

Figure 11 Laser Ranger Image of CCD Image (Figure 10)

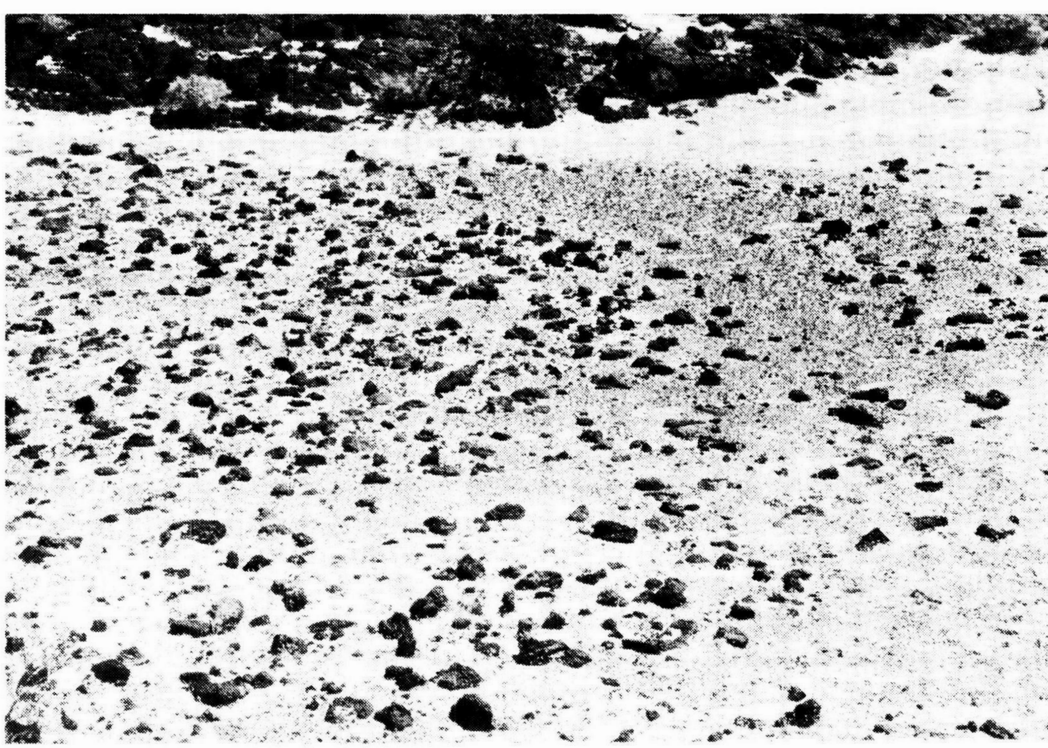

Figure 12 Photograph of Mars-Like Amboy Lava Field

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Figure 13 Photograph of Mars-Like Amboy Lava Field

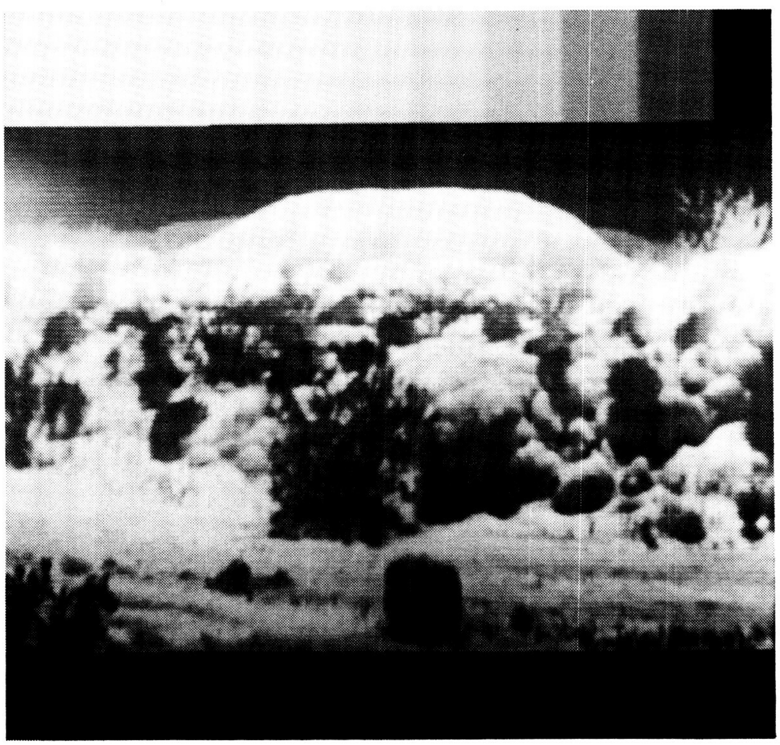

Figure 14 Infrared Image of Amboy Lava Field and Crater

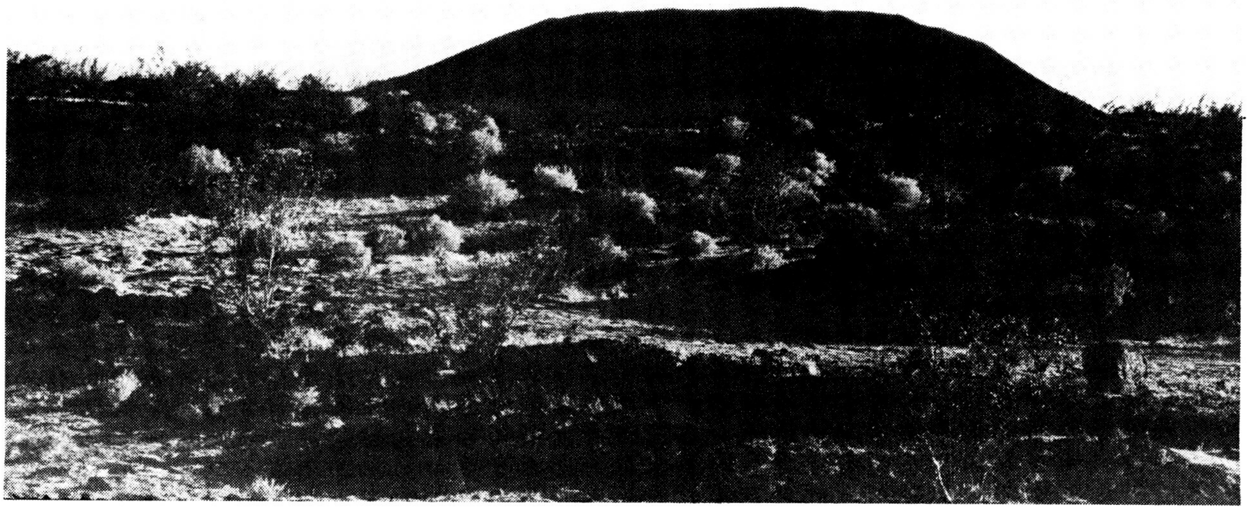

Figure 15 Photograph of the same areas as Infrared Image, (Figure 14).

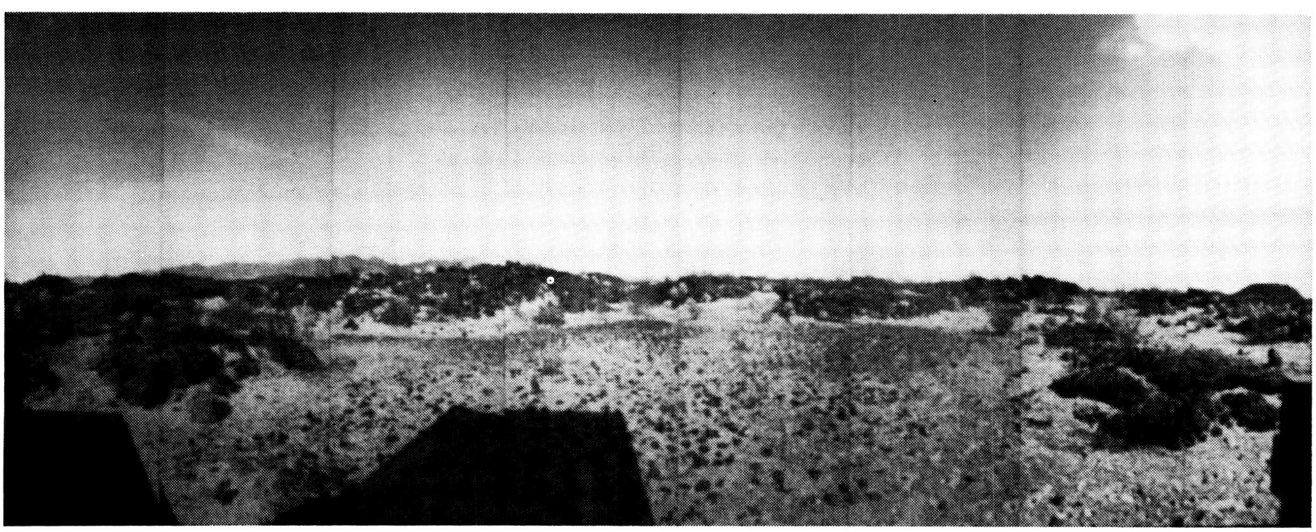

Figure 16 Panorama of Narrow Field-of-View Image of Amboy Lava Field

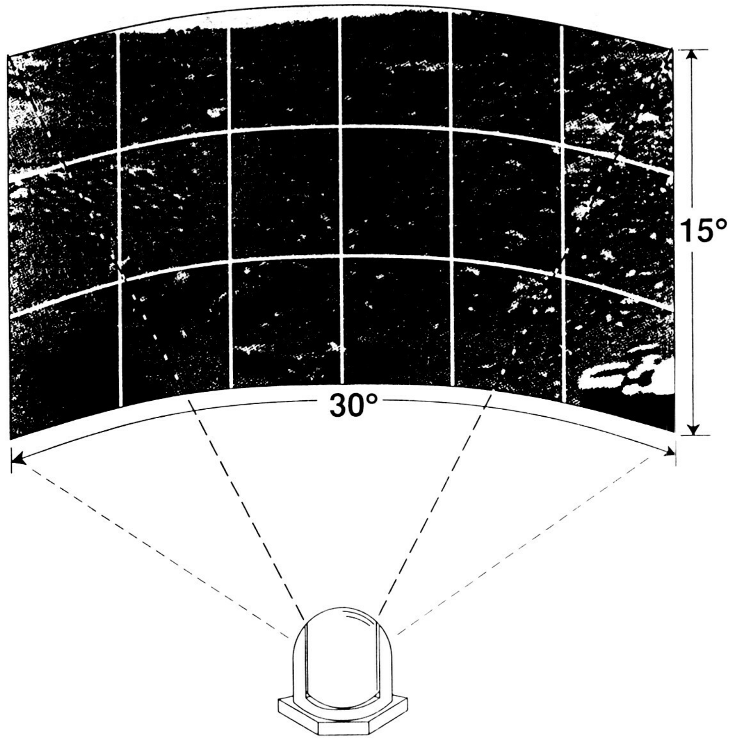

Figure 17 Artist's Conception of Mars Panorama Using Actual Viking Mars Image.