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Final Report - Proximity-Vision System for Protoflight Manipulator Arm

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Prepared for

Marshall Space Flight Center
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Introduction

Control systems for complex manipulatory tasks require precise information of errors in position, orientation, and velocity of the manipulator hand with respect to the object to be manipulated. This is particularly true in the final approach trajectory just prior to contact between the hand and object. In order to provide this information in a form usable by a human operator or a computer control system (or both) the National Engineering Laboratory of the National Bureau of Standards has developed for Marshall Space Flight Center a Proximity-Vision System suitably configured to mount on the MSFC Protoflight Manipulator Arm (PFMA). This Proximity-Vision System is a breadboard system built in order to demonstrate the capabilities and analyze the problems associated with using such a system in a real-time control mode. This report describes the theory of operation and the physical and electrical components of the breadboard hardware delivered to Marshall Space Flight Center. Performance testing of this hardware is to be done by the recipient.

Technical Approach

A block diagram of the NBS Proximity-Vision System is shown in Figure 1. This system consists of two separate but complementary subsystems.

1. A solid-state TV camera with 128 x 128 resolution elements is mounted on the wrist of the PFMA just behind the fingers, as illustrated in Figure 2. This camera is positioned so that its 36 degree field of view covers the manipulator fingers and a region extending one meter in front of the fingers. A photograph of the camera is shown in Figure 3.

Coordinated with this camera is a high intensity strobe flash system with optics which projects a thin fan-shaped plane of light into the region viewed by the camera in front of the PFMA fingers. A photograph of the flash system is shown in Figure 4. Any diffusely reflecting object within the region in front of the fingers reflects the light beam. The apparent position in the camera field of view of the reflected light makes it possible to compute the distance of the reflecting object by simple triangulation. The offset between the camera and the plane of projected light determines the relationships between the distance and the apparent position of the reflected light.

The fact that the projected light is a plane means that the intersection of the plane with a solid object will produce a reflected line of light as shown in Figure 5. The position of this line indicates distance. Its shape conveys information concerning the depth profile of the object being illuminated, and its end-points indicate the position and spacing of the edges to be grasped. This is illustrated in Figure 6 and 7.

2. The second subsystem of the NBS Proximity-Vision System consists of a pair of close-range infra-red proximity sensors imbedded in the tips of a pair of fingers suitable for mounting on the PFMA. A photograph of the fingers is shown in Figure 8. Two light emitting diodes, one on each finger, project chopped infra-red light into the region immediately in front of the fingers. Two photo-transistors, also one on each finger, collect light reflected from any diffusely reflecting object immediately in front of or between the fingers. This is illustrated in Figure 9. The modulated light is synchronously detected in order to discriminate against background illumination.

These short-range detectors are sensitive in the range of 0 to 20 centimeters and measure only the strength of the reflected light. Since the albedo of the reflecting object influences the strength of the reflected infra-red signal, this subsystem provides only relative position information unless the signals are calibrated in the region when both the solid-state camera-flash system and the short range infra-red system overlap.

These short range detectors provide a measure of redundancy to the system, particularly in the last few centimeters before contact. They also provide centering information for large objects which overflow the field of view of the camera-flash system at very close range.

Display-Control Console

Also included in the Proximity-Vision System is an operator display-control console. A TV viewing monitor displays the video signal from the solid state TV camera. Brightness controls on the monitor and push buttons for remote adjustment of the "f" stop on the camera enable the operator to optimize picture quality. The strobe flash is syncronized with the camera frame rate so that the reflected line of light appears as a pulsing cursor superimposed on the image. There is a selector switch which enables the operator to choose the pulse rate over the range from 3 per second to one every 1.5 seconds.

Data from the infra-red system is displayed on the same monitor as the 128 x 128 camera data. Intensity of reflected light from the two sensors is displayed as lengths of two bright lines running up the right and left sides of the camera display raster. The length of each line is proportional to the intensity of the signal detected by the respective sensor.

Computer Interface

The display-control console also contains a computer interface which can be used to interface the camera-flash system with a computer.

The video signal from the TV camera is converted to a series of 8 bit values by an analog to digital converter in the control console. Synchronization with the computer is provided via a data accepted pulse from the computer. When in the computer mode (which is selected by a switch on the front panel of the control console) the video clock is interrupted after each A/D conversion until the computer reads the 8 bit word and sends a data accepted pulse.

Conclusions and Recommendations

A full series of operational tests of the NBS Proximity-Vision system with the MSFC Protoflight Manipulator Arm remains to be done under the auspices of MSFC personnel. However, preliminary tests performed prior to and during delivery and installation of the system on the PFMA suggest several areas of further work.

1. Picture Quality

a) The intensity of the flash should be controlled so that it can be increased for large distances and decreased at short range. Preferably this should be accomplished automatically. This would best be done with a microprocessor which measures the received signal and adjusts the strobe intensity accordingly. The strobe intensity is best controlled by varying the duration of the flash.

b) The flash repetition rate should also be varied so that it is inversely proportional to distance. Thus as the manipulator closes on an object and the intensity of the strobe decreases, the rate of the flashing strobe would increase. This could also be accomplished by a microprocessor.

c) The iris adjustment to optimize the picture quality should also be placed under microprocessor control.

2. Slip Ring Requirements

The PFMA has a continuous wrist-roll capability such that the electrical connections between the operator-display control station and the manipulator wrist must pass through a set of slip rings. The NBS Proximity-Vision system in its present breadboard form has a total of 23 leads which cross the continuous wrist-roll interface. Because it is a breadboard only no serious attempt was made to minimize the number of leads or to operate through the existing slip rings.

Future versions of the Proximity-Vision system will need to address this slip ring problem. It would be possible to reduce the required number of slip rings to 17 by allowing several of the subsystems to share power supply voltages. This would require additional filtering of supply voltages to prevent cross talk. Additional savings in slip ring requirements might be made by eliminating the End-of-Line and End-of-Frame sync signals and by putting the video clock generator on the wrist. This would require the design of additional circuitry to reconstruct these sync signals from the composite video.

The absolute minimum number of slip ring connections are as follows:

Camera

1. +15
2. -15
3. GND
4. Video
5. Strobe

Flash

6. +300 volts (or +5 volts with 3 amps capacity)
7. GND
8. Trigger

IR Sensors-Emitters

9. Output #1
10. Output #2
11. +5 volts
12. GND

Iris Adjust

13. Motor Winding +
14. Motor Winding -

3. Computer Analysis of Proximity-Vision Data

It is recommended that a continued development effort be undertaken to make possible the automatic extraction of range and position data from the proximity vision system. This would make possible computer assisted terminal guidance and control of the manipulator in grasping objects, extracting modules, and performing various other tasks which will be required of the PFMA and similar systems in the future. The advantages would be increased precision, speed, and dexterity of terminal movements, reduced operator fatigue, and improved reliability and safety.

As a first step toward this goal, NBS recommends:

a) A microcomputer system for automatic image quality and flash intensity and rate control. It is recommended that this be a separate microcomputer from the PDP-11/35 which will control the arm because of the unique demands of the video interface. Although it would be possible to connect the Proximity-Vision system directly to the arm control computer through a suitably configured interface, this is not recommended because of the potential software problems due to conflicting timing requirements of the two real time control systems.

b) A hardware frame-to-frame compare and threshold system so that the line of light produced by the flash can be automatically separated from the background image. A block diagram of such a system is shown in Figure 10.

c) Software for feature extraction so as to automatically measure target parameters such as:

- o distance
- o closure rate
- o size
- o orientation
- o depth profile

A block diagram of the recommended computer analysis system is shown in Figure 11.

FIGURES

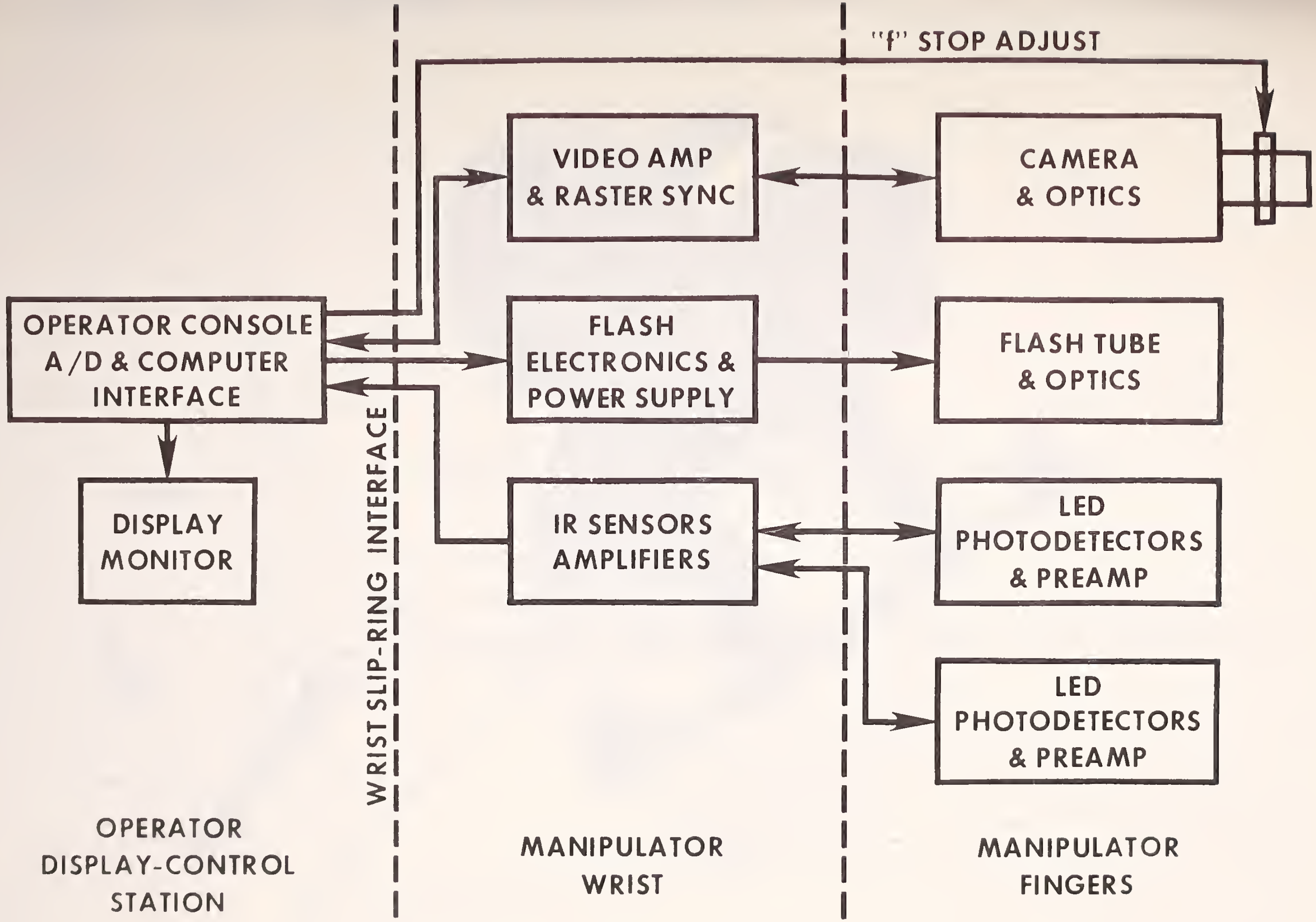

FIGURE 1: A block diagram of Proximit Vision System

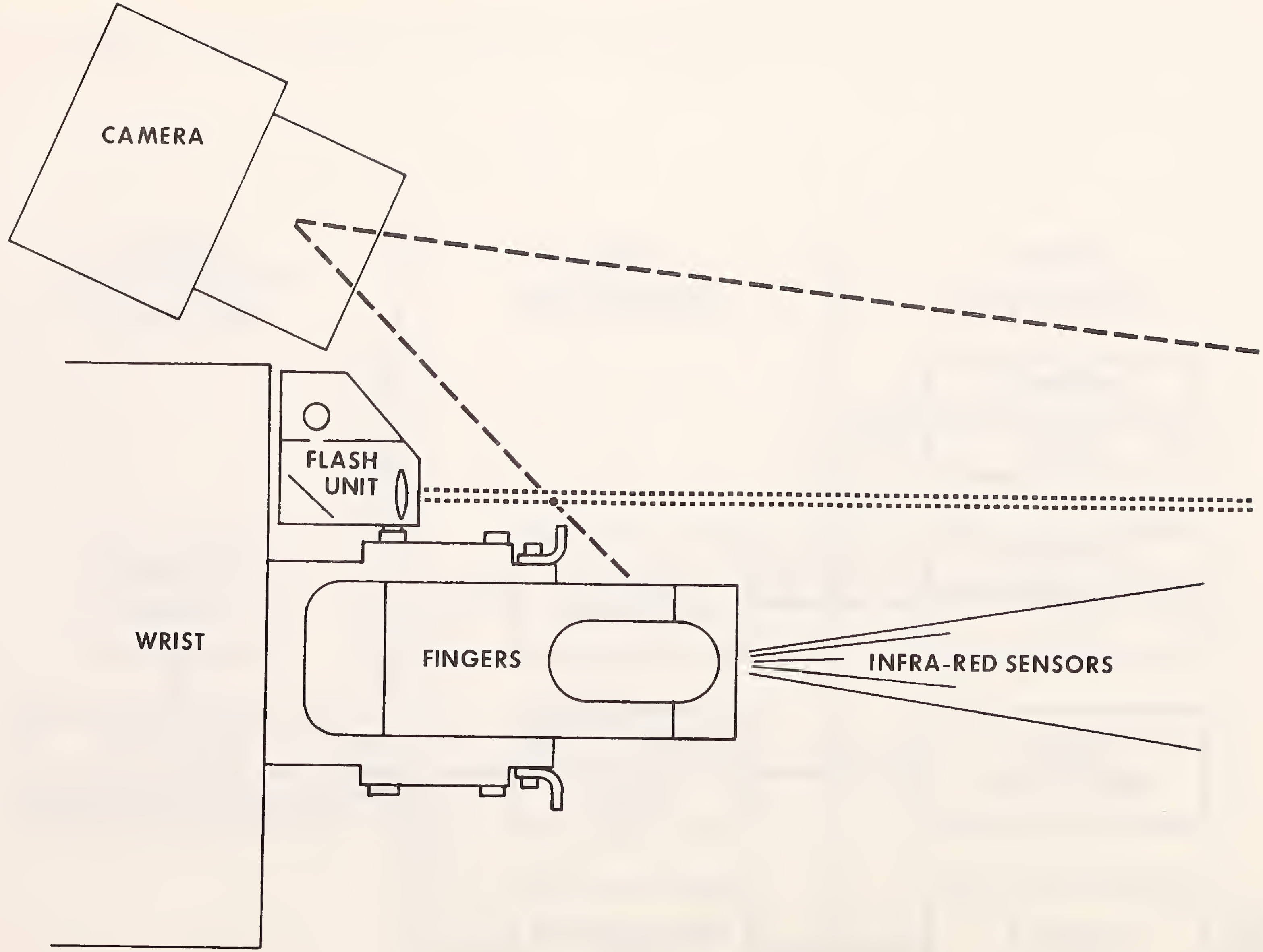

FIGURE 2: Mounting configuration of the Proximity Vision System

FIGURE 3: The 128 X 128 solid state TV camera with mounting bracket and iris adjust mechanism.

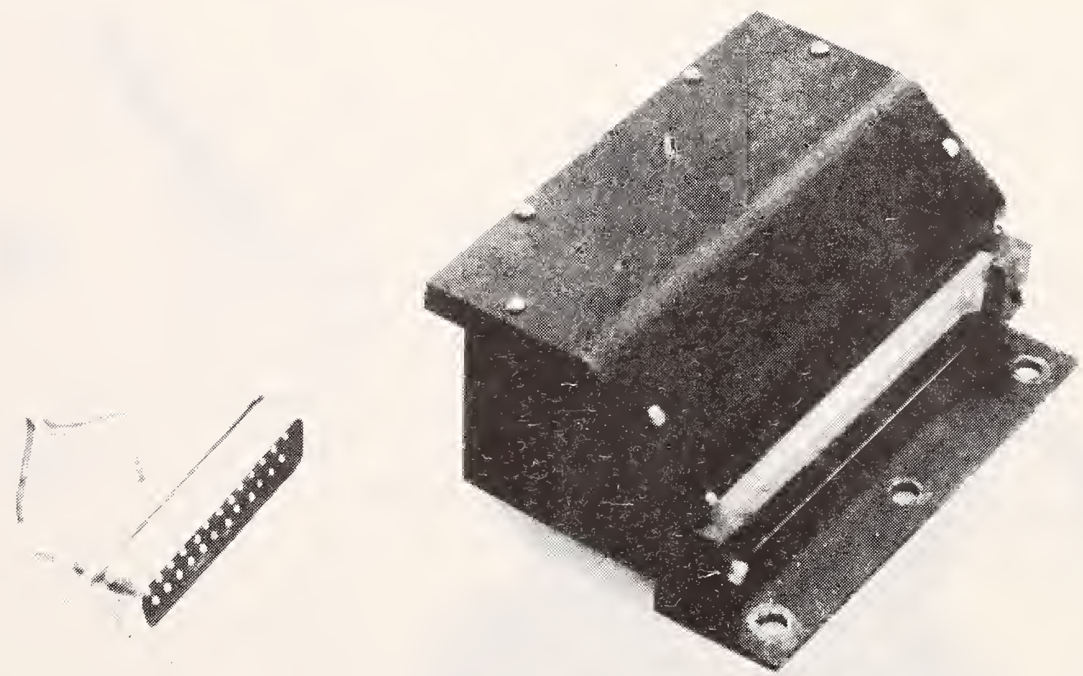

FIGURE 4: The flash head which generates the plane of light

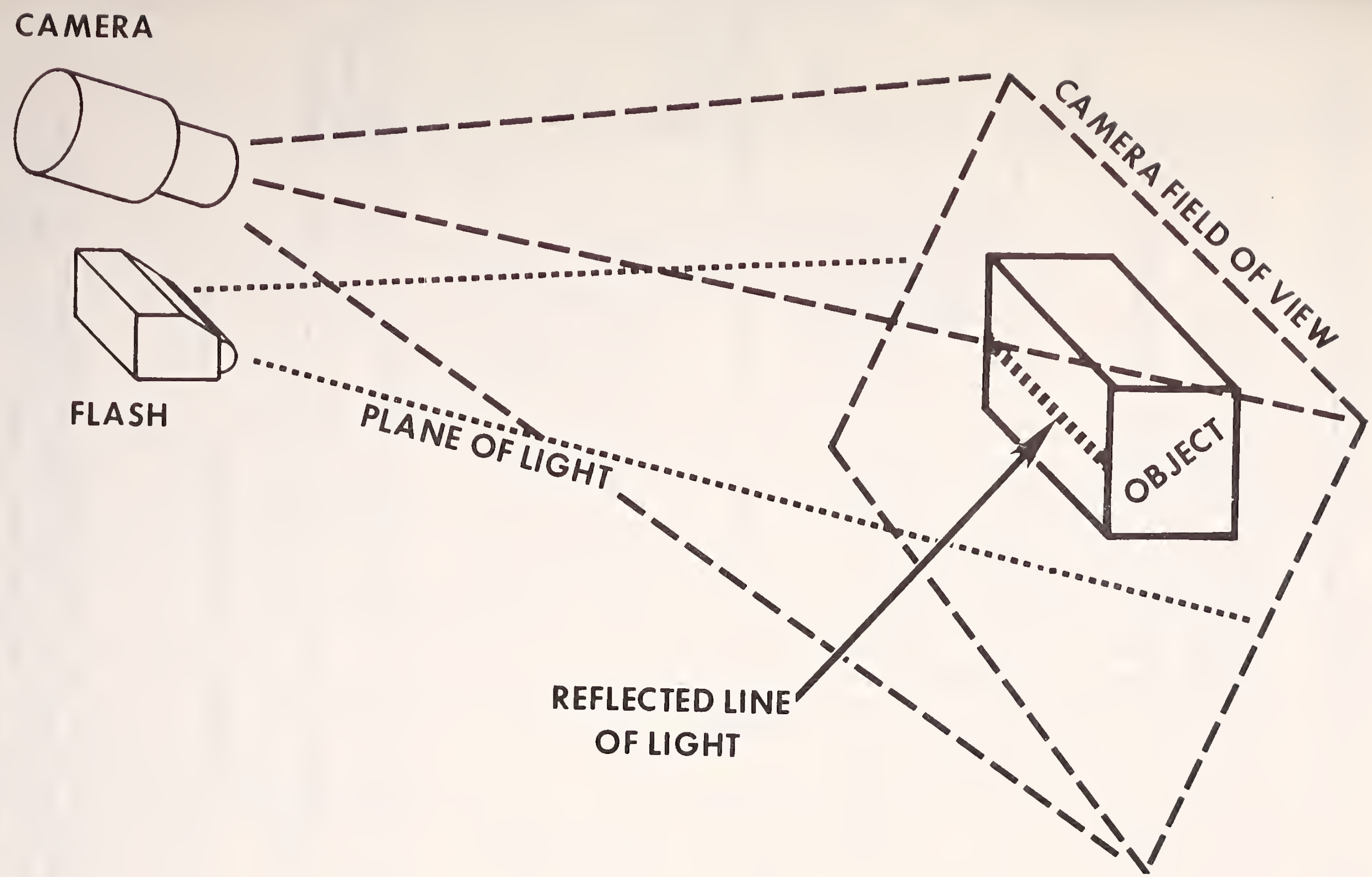

FIGURE 5: Relationship between the camera field of view, the plane of light and a viewed object

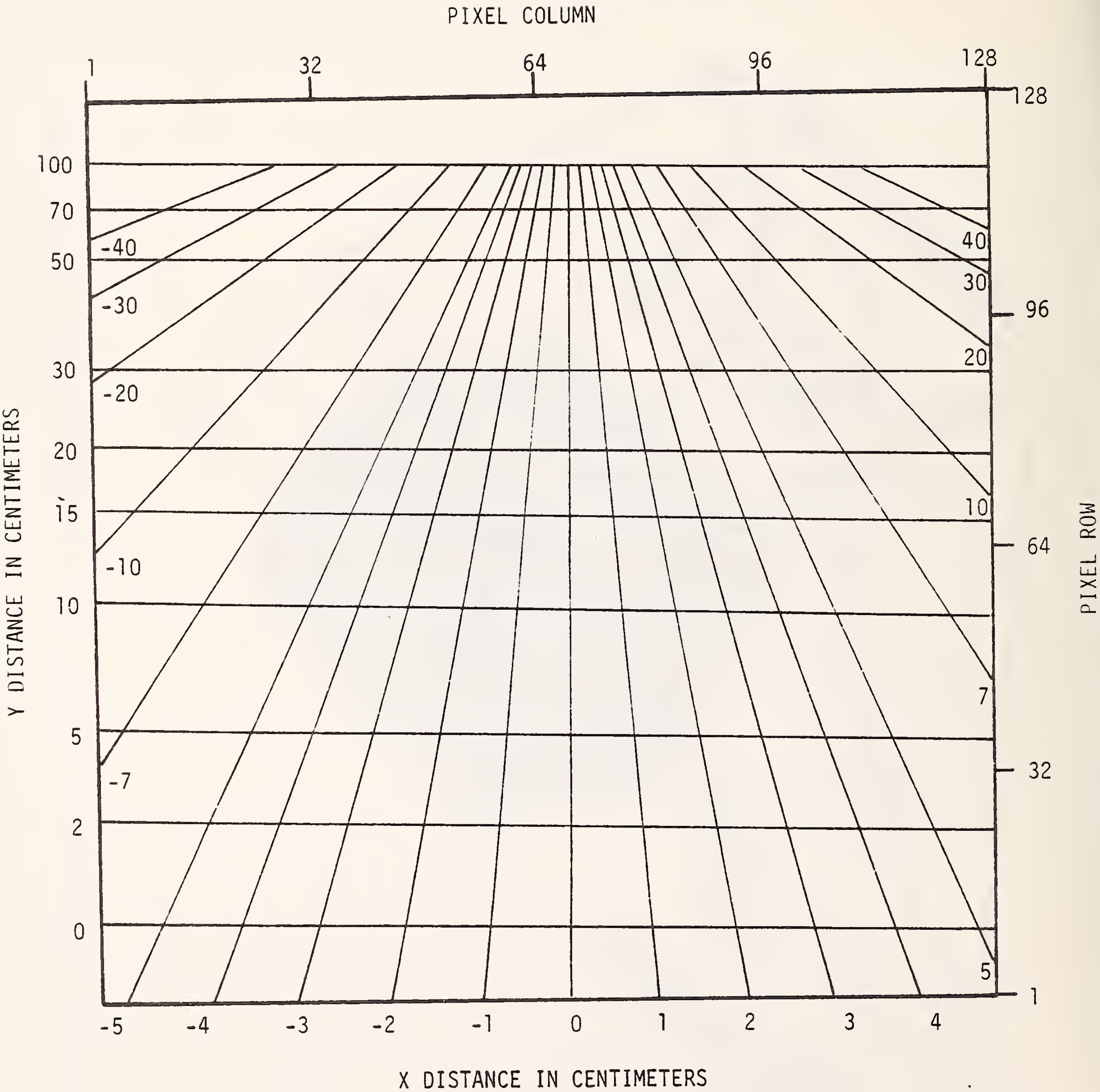

FIGURE 6. A range graticule which when placed over the viewing monitor gives the distance to any point on a reflected line of light. The X and Y distances are measured in the coordinate system of the fingers. The X axis passes through the two finger tips and the Y axis is parallel to the wrist axis. The slight tile in the figure is due to a misalignment of the chip in the camera.

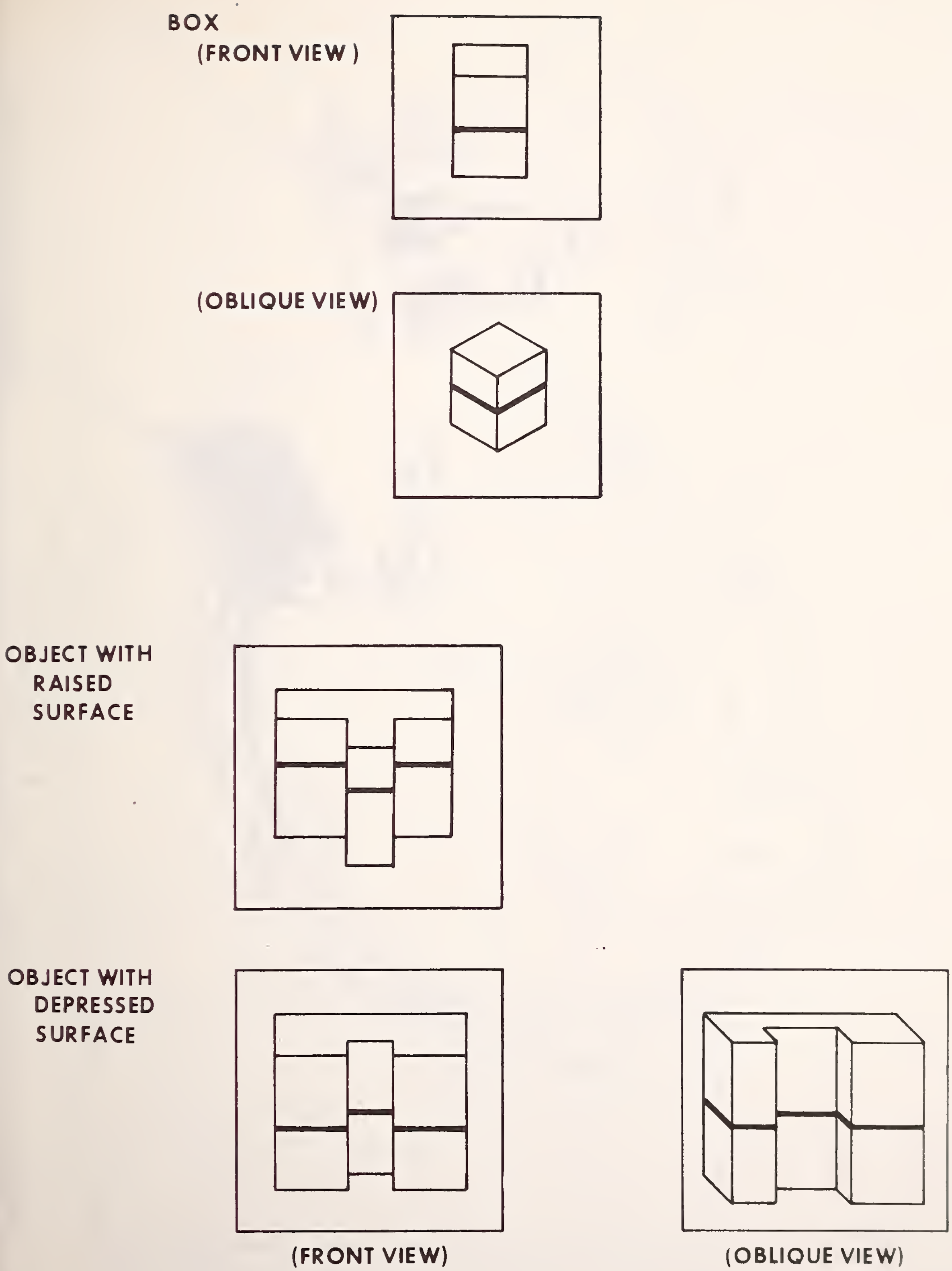

FIGURE 7: Illustrations of various shaped objects viewed through the monitor. The reflected line of light is shown as a heavey black line across each object.

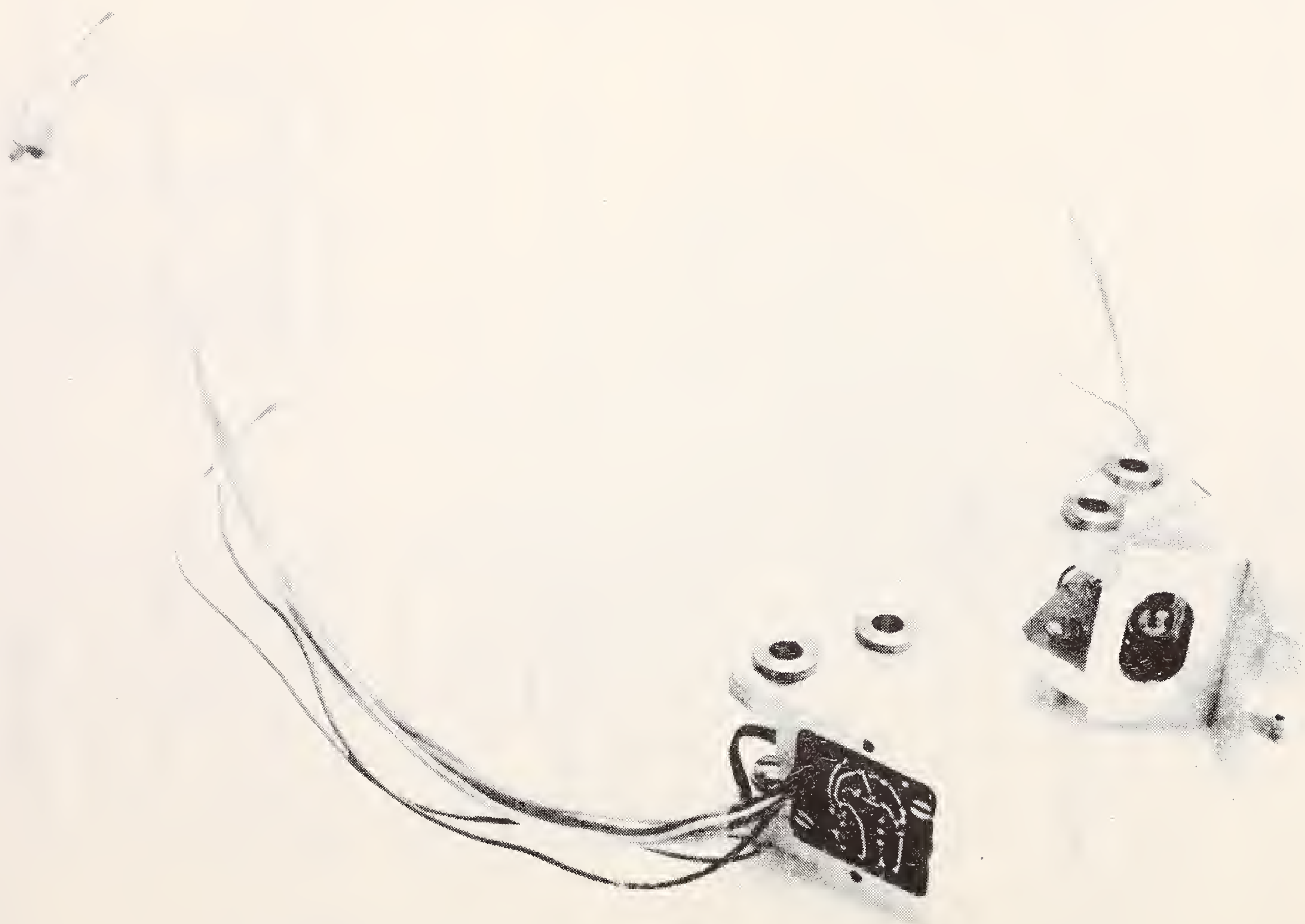

FIGURE 8: PFMA finger tips containing the close-range infra-red proximity sensors

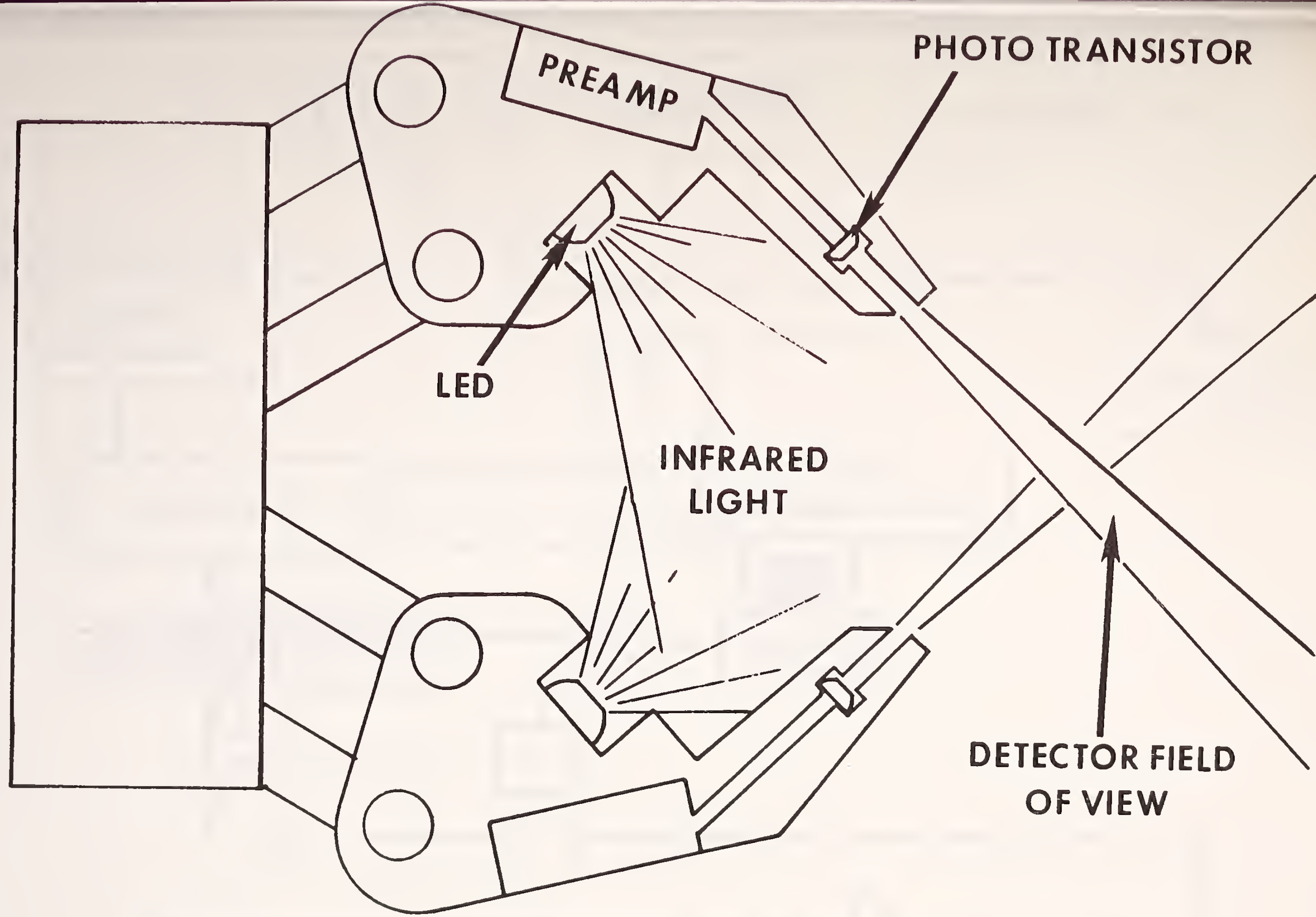

FIGURE 9: A drawing illustrating the relative position of the light emitting diodes (LEDs) and proximity sensors.

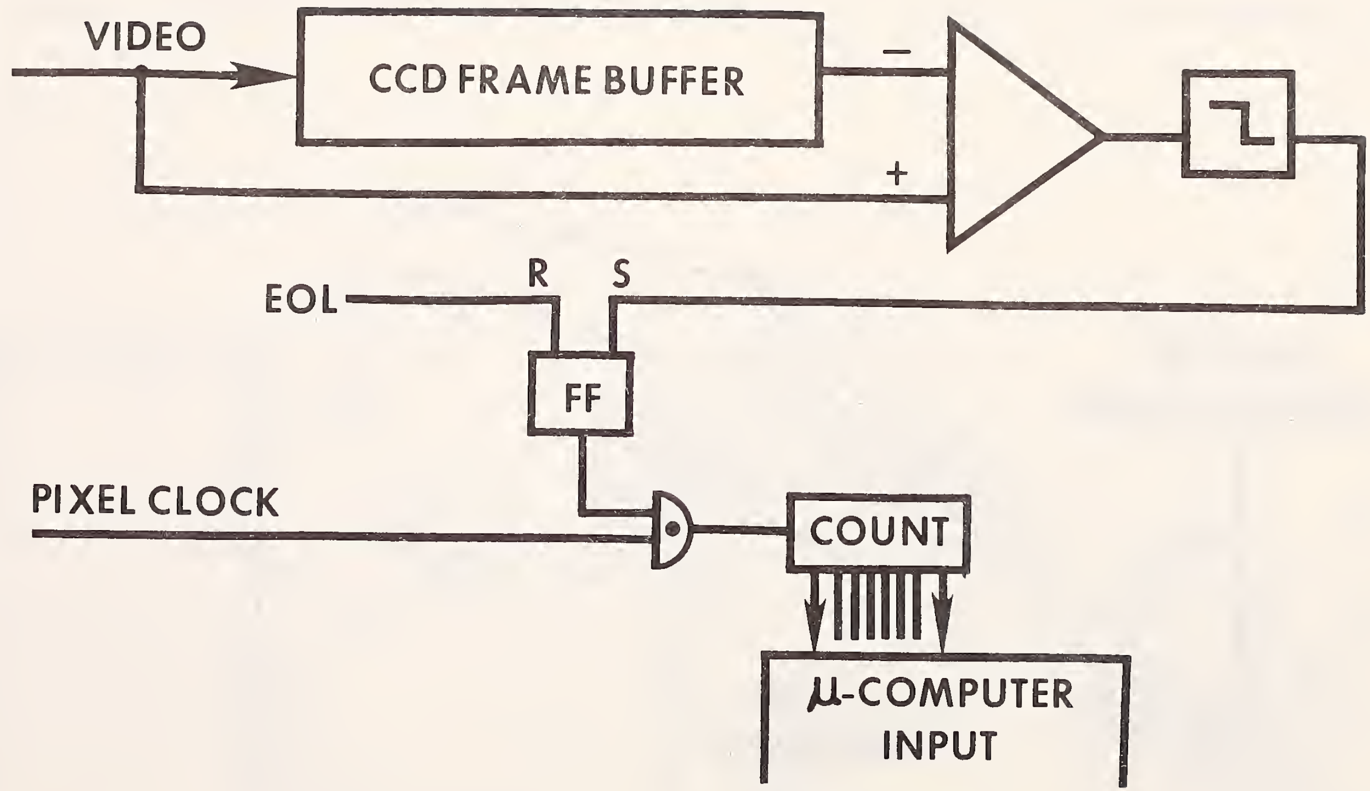

FIGURE 10: Block diagram of a hardware frame-to-frame compare system for automatic extraction of the line of light from background illumination.

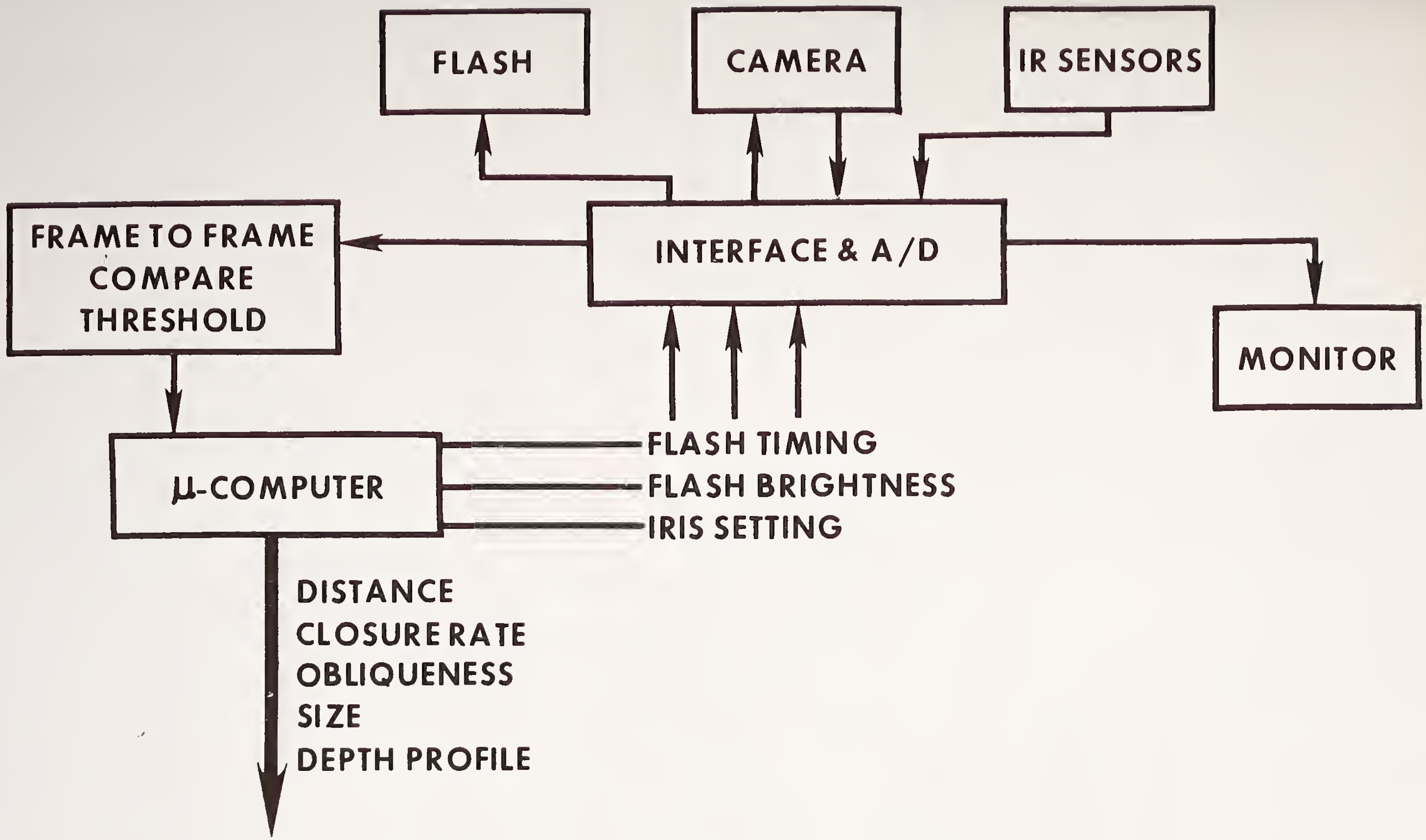

FIGURE 11: Block diagram of recommended system for automatic control of image quality and extraction of target features.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The NBS Proximity-Vision System consists of two separate but complementary subsystems: 1) A solid-state TV camera with 128 x 128 resolution elements mounted on the manipulator wrist. Coordinated with this camera is a high intensity strobe flash system with optics which project a thin fan-shaped plane of light into the region viewed by the camera. 2) A pair of close-range infra-red proximity sensors mounted in the fingertips.

The system is built for a manually controlled teleoperator. However, the design is also suitable for computer image analysis in the control of an autonomous robot manipulator.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Depth image; proximity sensor; robot vision; teleoperator vision; wrist-mounted TV

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