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THE IMPACT OF SENSOR-SCENE INTERACTION ON THE DESIGN OF AN IR SECURITY SURVEILLANCE SYSTEM

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ABSTRACT

Recent encouraging developments in infrared staring arrays with CCD readouts and in real time image processors on and off the focal plane have suggested that technologies suitable for infrared security surveillance may be available in a two-to-five year time frame. In anticipation of these emerging technologies, an investigation has been undertaken to establish the design potential of a passive IR perimeter security system incorporating both detection and verification capabilities.

To establish the design potential, it is necessary to characterize the interactions between the scene and the sensor. To this end, theoretical and experimental findings were employed to document (1) the emission properties of scenes to include an intruder, (2) the propagation and emission characteristics of the intervening atmosphere, and (3) the reception properties of the imaging sensor. The impact of these findings are summarized in the light of the application constraints. Optimal wavelengths, intruder and background emission characteristics, weather limitations, and basic sensor design considerations are treated. Although many system design features have been identified to this date, continued efforts are required to complete a detailed system design to include the identifying processing requirements. A program to accomplish these objectives is presented.

1.0 INTRODUCTION

High resolution infrared (IR) imagery with covertly placed cameras has remained an attractive solution over the years for remote surveillance of sensitive areas. The practicality of this approach has been limited by the cost and lifetime of the sensor and its associated image processor. However, recent encouraging developments in staring IR arrays requiring little or no cooling and in real time image processors working on or off the focal plane have suggested that technologies suitable for continuous infrared surveillance may be available in a two-to-five year time frame. In anticipation of these developments, an investigation has been undertaken to establish the design potential and utility of a passive IR imaging system for a perimeter security application. Both detection and verification aspects of the sensor system are under consideration.

In order to establish the design potential of an IR surveillance system, it is necessary to characterize the interactions between the scene and the sensor. These interactions are illustrated conceptually in Figure 1. In addressing the interaction, one must document the radiation characteristics of the scene to include an intruder. The radiance distribution is governed by the physical temperature, emissivity (ε) and reflectivity (ρ) of objects in the scene. Radiations propagating to the receiver from the scene can be altered considerably by the absorption, scattering, and emissive properties of the intervening atmosphere as caused by water vapor, haze, fog, snow, rain, and smoke. In this regard, atmospheric effects perhaps play a more important role in security applications than in tactical applications simply because the sensor must operate continuously in most any environment. The radiation arriving at the sensor is further altered by the optics, polarizer (if installed), detector, and the post detection amplifiers.

A joint analysis of the scene, atmosphere, and sensor characteristics in view of the application constraints is vital in identifying the performance and design potential of a candidate IR sensor system. In particular, the outcome of such a joint analysis is helpful in establishing (1) the optimal spectral band, (2) the appropriate spatial resolution, (3) the necessary temperature (radiation) resolution, (4) the detector sensitivity, (5) the sensor design configuration, (6) environmental conditions which limit the performance of the sensor, and (7) image processing requirements to enhance the performance of the sensor under adverse as well as normal conditions. Optimal design choices are necessary to assure sufficient contrast occurs between the intruder and his background to maximize the probabilities of a valid detection and a valid assessment and to minimize the probability of a false detection

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and a false assessment. The final choice in the system design is also influenced by the existence of a hardware technology to support the design and by the application cost constraints. These considerations have been treated elsewhere(1) and will not be included here.

The current findings as relate to the scene, atmosphere, and sensor are presented. Although these findings indicate a partial design potential for an IR surveillance system, a stronger empirical basis for this application is required to fully demonstrate the capabilities and limitations of this sensor approach. To this end, a program plan centered on collecting, analyzing, and enhancing imagery gathered in the field under realistic conditions is presented here. However, before addressing these results, the deployment of IR imaging sensors in relationship to the perimeter security concept is first described.

2.0 APPLICATION OF IR IMAGERS TO PERIMETER SECURITY

An idealized illustration of a sensitive installation to be secured is shown in Figure 2. The installation is surrounded by an interior fence and an exterior fence. The separation between fences is typically 10 metres. One or more intrusion detection sensor types are installed in the gap between the fences to provide overlapping coverage about the entire perimeter. Alarms are identified by sectors (typically 100 metres long) and are validated either visually or by closed circuit television (CCTV). Validated alarms initiate a response force.

IR imaging sensors may be used in place of the CCTV or as a security sensor in its own right. When replacing the CCTV, a considerable reduction in nighttime illumination can be realized. In either case, both intrusion detection and validation roles can be served by the IR sensor. Figure 3 illustrates how two imagers can be deployed along the perimeter to provide overlapping coverage. Through the use of wide angle optics, the IR cameras can also be installed within the area to provide coverage over a sector. In this case, the field of view must be cleared of obstacles and the IR camera must stare through and above the fabric of the interior fence.

The key to successful use of IR imagery for intrusion detection lies in the design and realization of an imaging processing system to provide alarm and validation capabilities. A suitable processing concept is illustrated in the block diagram of Figure 4. The processing is separated into two channels. The upper channel is devoted to the detection and alarm function. In that channel, the background is suppressed to enhance short term changes in the scene. The spatial resolution is degraded to reduce the number computations. Then, motion of the changes and their trajectories are identified. Suitable trajectories admit alarms. The lower channel performs the validation function. The primary objective in the lower channel is to provide suitable image products for display when an alarm occurs. The image must be enhanced to make evident intruders in low contrast and cluttered backgrounds. Background information from the upper channel may be used to enhance the image. The intruder can also be emphasized by adding scene changes to an enhanced image. The remaining portion of the verification branch entails image compression, storage, and retrieval. The retrieval function is cued from the upper channel or by other sensors.

3.0 THEORETICAL AND EXPERIMENTAL FINDINGS

This section presents a brief summary of current findings which guide and validate the design direction of an IR intrusion detection and verification system. The results are categorized into scene, weather, and sensor related findings.

Scene Related Findings - Several useful atmospheric windows between 3-5 microns (middle IR) and between 9-13 microns (far IR) occur in the IR spectrum. A simple system must choose between them. In a comparison of the thermal emission characteristics of these two bands, it is noted that at terrestrial temperatures the emission peaks in the far IR band as illustrated in Figure 5. From this illustration, it can be shown that temperature differences as well as emissivity differences produce larger changes in emissions in the far infrared band in comparison to the near infrared band. For AC coupled sensors operating at comparable noise levels, this implies higher contrast images can be realized in the far infrared spectrum. In addition, sensors operating in the far infrared experience significantly less variation in emissions resulting from reflections of solar flux and from cloud shadows. As a consequence, better detection, better enhancement, and fewer solar related nuisance alarms are anticipated in the far IR band.

Several pilot experiments were conducted to document the radiation characteristic of a heavily clothed intruder and to evaluate the difficulty of observing an intruder in a cluttered background. An AGA Thermovision operating in the near and middle IR spectrum provided the imagery. The results of these experiments are thought to apply equally as well to observations in the far IR spectrum.

In these experiments, it was observed that a heavily clothed intruder tended to radiate at apparent temperatures near the ambient temperature as illustrated by the thermogram of Figure 6. The blue areas are only 0.2°C above ambient, whereas the green areas in the illustration represent an apparent temperature of 1.9°C above ambient. The magenta areas are 3.1°C above ambient. Outdoors, where advection is often effective, the apparent temperature difference may even be smaller. These observations imply that when the background and ambient temperatures are similar, the contrast of a heavily clothed intruder with the background can be conceivably low. Of course, any exposed areas will assist in detecting an intruder as indicated by the face in Figure 6 (yellow area).

The contrast of a crawling intruder in two locations of a cluttered scene is illustrated in Figures 7a and 7b. The intruder crawled across a dirt road and approached a chainlink fence. While on the road (Figure 7b), the intruder is not discernible except for the contour of his head. On the other hand, he can be readily distinguished in the position between the road and fence (Figure 7a). These two illustrations document the importance of motion in designing the detection and verification channels of the image processor.

Weather Related Findings - The clarity of the atmospheric window in the two preferential bands is affected by the amount of water vapor along the line of sight. The variability in atmospheric emission and absorption is greater in the 3-5 micron band than in the 8-13 micron. Regardless, the IR visibility is never adversely affected by water vapor alone in these two bands.

In contrast, fog can degrade the IR visibility significantly even at the short ranges of interest. Transmission through fog becomes increasingly difficult as the fog density increases. However, the transmission at long IR wavelengths remains significantly better in comparison to the visible or short IR wavelengths. To compare the performance in fog at 4 and 10 microns, recent transmission data were applied to thermal radiation of an intruder $2^{o}C$ above background. The reduction in differential radiance at these two wavelengths was computed as a function of fog density in grams per cubic metre. The results are shown in Figure 8. It is noted that the differential radiance at 4 microns drops abruptly for fogs having a visual visibility of less than 230 metres (water content greater than $10^{-2}gm/m^3$). The poorer transmission at 4 microns will result in poorer image contrast and noisier images as the amplifier gain is raised in attempt to restore the contrast electronically.

Another mechanism which reduces contrast is rain. Unlike fog, transmission through rain is exceedingly good. Rain, however, causes loss of contrast through several other mechanisms. Rain tends to reduce elements in a scene to an isothermal condition. Furthermore, since the skin depth of water is small at IR wavelengths, the observed radiation will primarily arise from the water film. As a consequence, the scene elements will all tend to radiate like water at the same temperature resulting in poor image contrast. Evidence for this lack of contrast is demonstrated by comparing the IR images of Figures 9a and 9b.

Sensor Related Findings - Design guidelines and trade-off relationships were established for staring sensors. In particular, the potential of designing a passive IR imager with a focal plane array for a perimeter security application was demonstrated for a sensor operating in the 8-13 micron band or the 3-5 micron band. Among the current staring technologies, the pyroelectric array (PEA) and the Schottky barrier photodiode array (SBPA) exhibit the best potential for this application. The PEA is suitable for operation in the 8-13 micron band, and the SBPA is suitable for the 3-5 micron band.

The results of this study are too numerous and detailed to present and illustrate in the course of a paper. As a consequence, a summary of the findings is simply presented below:

1. Reasonably sized optical systems can be realized to achieve the necessary spatial resolution and fields of view at the ranges of interest. However, conventionally designed optical systems may yield marginal lengths of coverage (depths of field) when viewing along the perimeter at small F numbers. This constraint can be virtually eliminated, however, by tilting the focal plane array slightly to circumvent the depth of field problem.

2. Reasonable array sizes and geometries can be realized when the sensor views along the perimeter to obtain 100 metres of coverage. However, excessive array lengths are necessary to cover 100 metres of perimeters when viewing from inside the area. It is assumed here that the sensor is employed both for detection and verification purposes. Verification requires larger array sizes.

3. Demonstrated detector sensitivities for the PEA will yield temperature resolutions of $1^{o}K$ or better in clear weather. With projected improvements, resolutions of better than $0.1^{o}K$ are anticipated. The same improvements should also yield a $0.5^{o}K$ resolution at 200 metres in a fog having a (visual) visibility of 100 metres.

4. Demonstrated sensitivities for the SBPA will yield temperature resolutions of $0.15^{o}K$ in clear weather. With projected improvements, temperature resolution of better than $.05^{o}K$ are anticipated. However, in fog, the performance of the SBPA seriously degrades with or without improvements to a point where no reasonable temperature resolution can be specified.

5. The SBPA requires cryogenic cooling to temperatures below $85^{o}K$. The improved detector technology will probably require even lower temperatures. In contrast, the pyroelectric array requires no cooling.

4.0 PROGRAM/EXPERIMENT PLAN

Although good potential for the sensor design was demonstrated, it became apparent during the study that there is insufficient relevant data to make judgments regarding system performance under adverse conditions such as wet scenes, fog, clutter, wind motion, cloud shadows, dust, etc. Careful sensor selection and design can minimize these problems; however, the ultimate solution lies in appropriately processing the imagery in real time for detection and verification purposes.

As a consequence, a comprehensive experiment plan has been designed to establish an adequate data base specifically related to this application. The data base will be used to fully determine system design potential, to establish design guidelines, and to identify the processing requirements. The data base would consist of high quality IR imagery taken with a scanning sensor. Where necessary, the performance of a staring sensor would be inferred from the scanning sensor data. The image data base will be acquired through realistic field experiments using an image acquisition system similar to that illustrated in Figure 10. A high resolution TV compatible imager operating in the 8-12 micron band will provide image sequences. The sequences will be recorded on a video cassette recorder or sampled by a digital frame grabber. A minicomputer will control the digital acquisition system. A digital interface to a portable meteorological station will be used to document weather and insolation conditions. Other experiment data may be entered via the teletype terminal. All digital data, whether imagery or experiment conditions, will be stored on magnetic tape or floppy disks.

Various experiments have been designed to characterize the sensor, scene, and weather effects. The experiment objectives include:

1. Identify the spatial and temperature resolution to detect and recognize intruders in various backgrounds.

2. Determine sensor performance in fog and rain and develop detection and verification enhancement methods.

3. Document the diurnal emission characteristics of various backgrounds with intruders present.

4. Evaluate performance in high winds and develop method to compensate for camera motion.

5. Document cloud shadow effects and develop discrimination methods if necessary.

5.0 Conclusions

Good design potential for an IR staring sensor has been demonstrated for a perimeter security system. Reasonably sized arrays and optical systems were identified to achieve the necessary spatial resolution. The anticipated temperature resolution requirement may be provided by several emerging array technologies. The PEA shows good promise in providing continuous surveillance. Hopefully, improved PEA sensitivity and reliability will be demonstrated shortly. Cryogenically cooled sensors are not yet cost effective for long term and continuous operation. Some promise may exist in thermoelectrically cooled arrays. However, uniform array sensitivity must yet be demonstrated.

The detection and verification performance of an IR security surveillance system requires careful examination. Although an optimal spectral band has been identified, theoretical and experimental findings suggest potential degradation in performance under certain adverse conditions. The degree of degradation must be documented and, if necessary, means of enhancing the performance through image processing identified. Once the processing requirements have been defined, means of implementing the processing must also be identified. Projected developments in very high speed integrated circuits will be helpful in this regard.

The above observations indicate that full-scale development of an IR security surveillance system must await further progress in detector arrays and processing hardware. Until then, the processing and system requirements must be further defined.

References

1. R. K. Petersen, et al, "Final Report: Infrared System Study and Technology Survey," Systems Engineering Division 1738, Sandia National Laboratories, Dec. 1981.

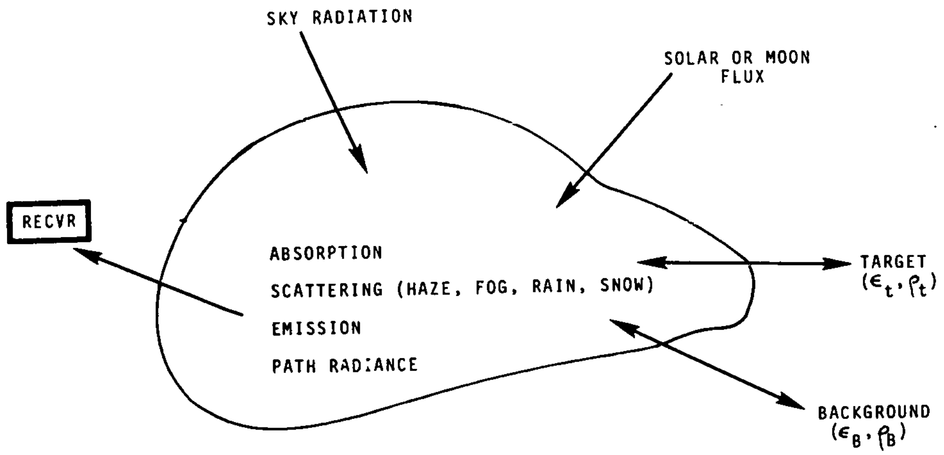

FIGURE 1. A CONCEPTUALIZATION OF THE SCENE-SENSOR INTERACTION

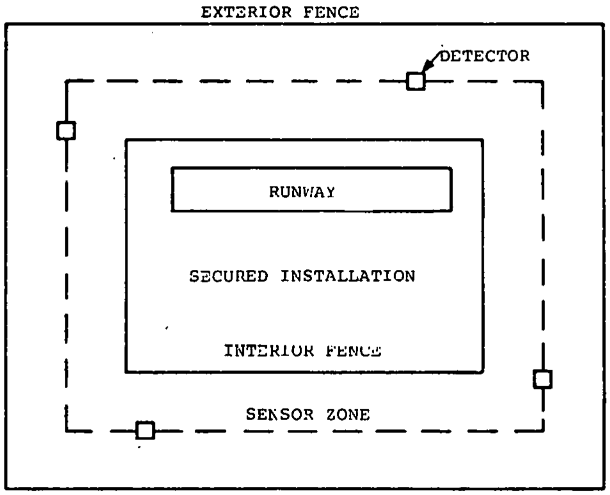

FIGURE 2. IDEALIZED SECURED INSTALLATION

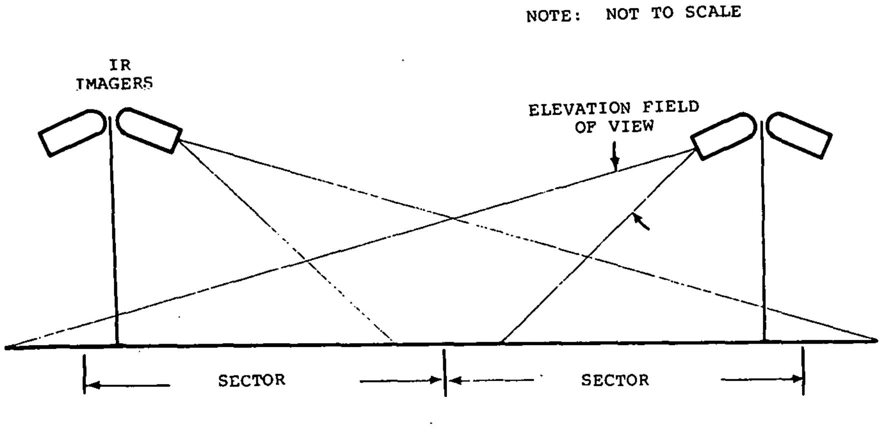

FIGURE 3. COVERAGE ALONG PERIMETER BY SECTOR

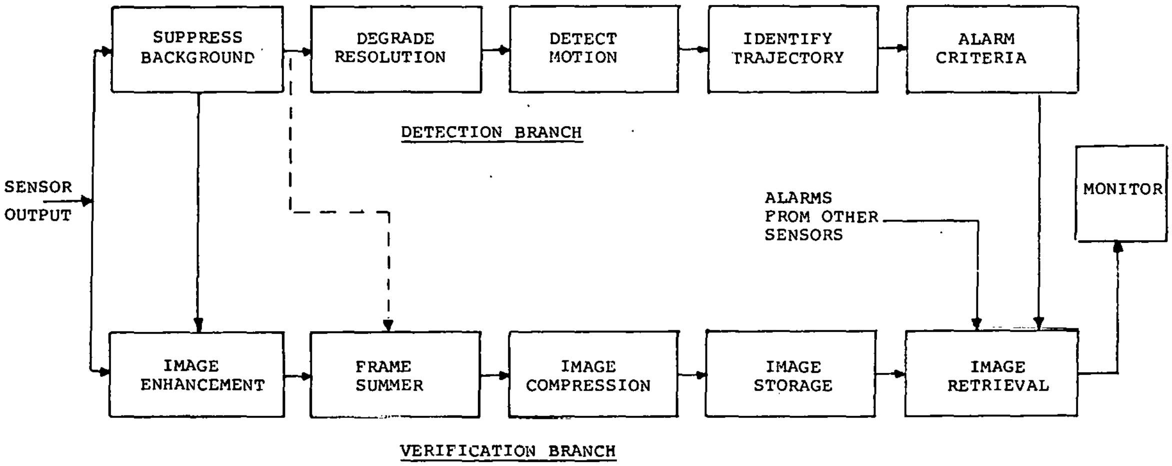

FIGURE 4. A PROCESSING CONCEPT FOR INTRUDER DETECTION AND VALIDATION

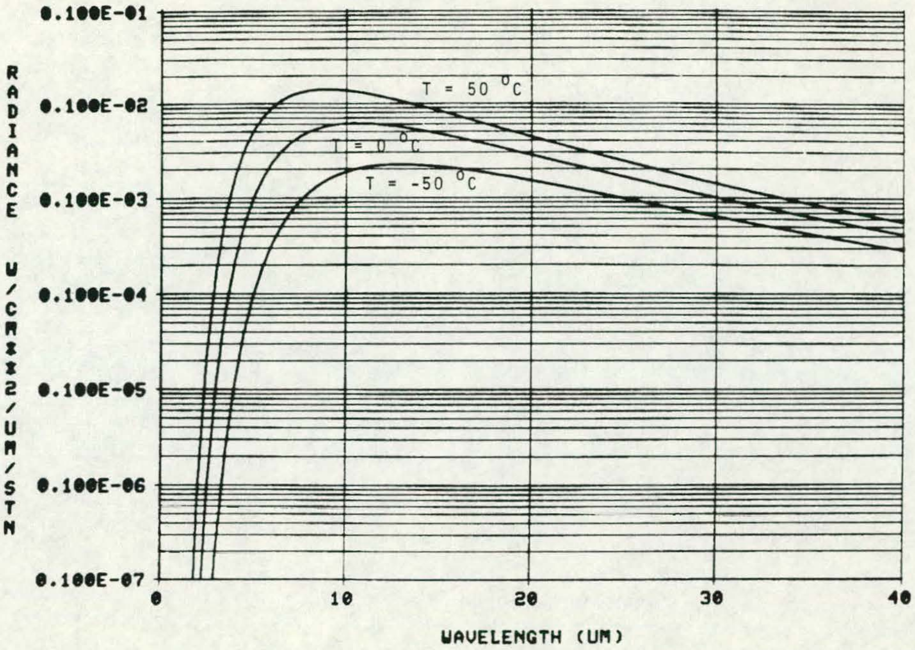

FIGURE 5. CHARACTERISTIC OF BLACKBODY RADIATION

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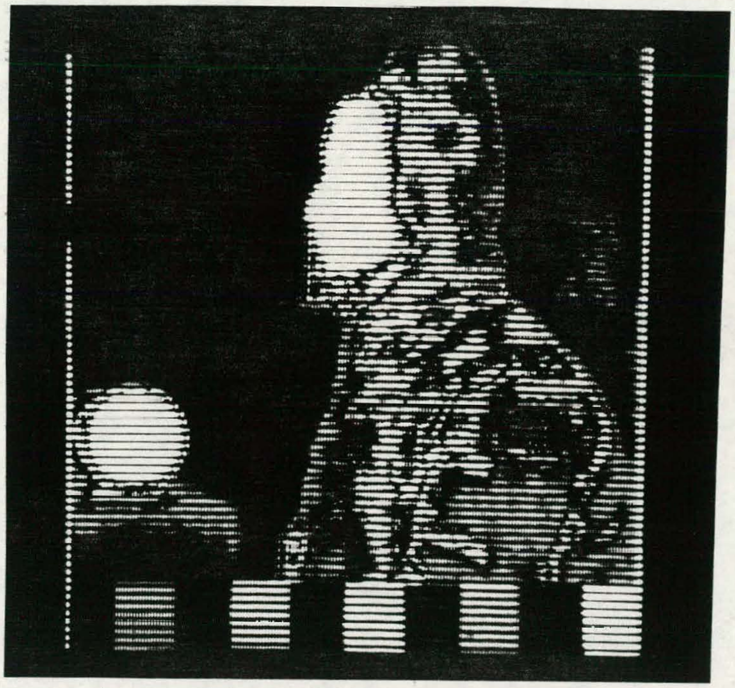


FIGURE 6. COLORIZED THERMOGRAM OF A HEAVILY CLOTHED INTRUDER (SIDE VIEW)

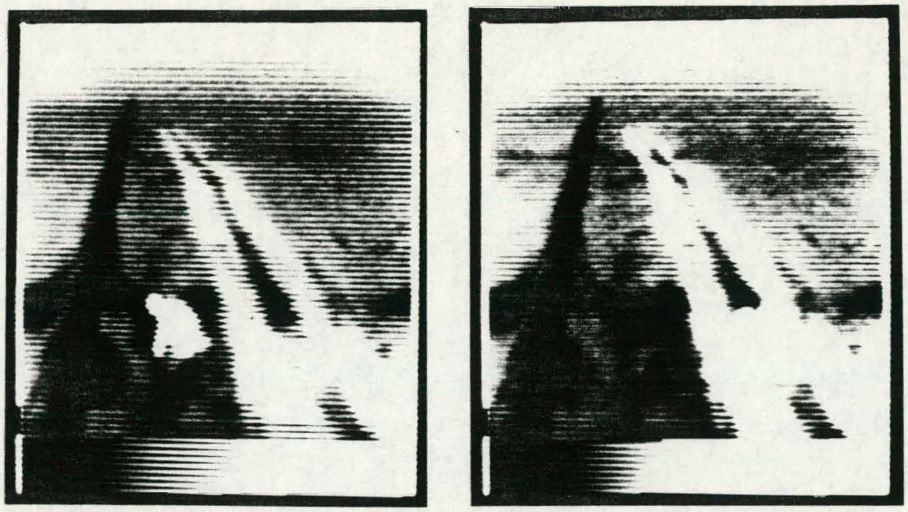


FIGURE 7. IR IMAGE OF A CRAWLING INTRUDER

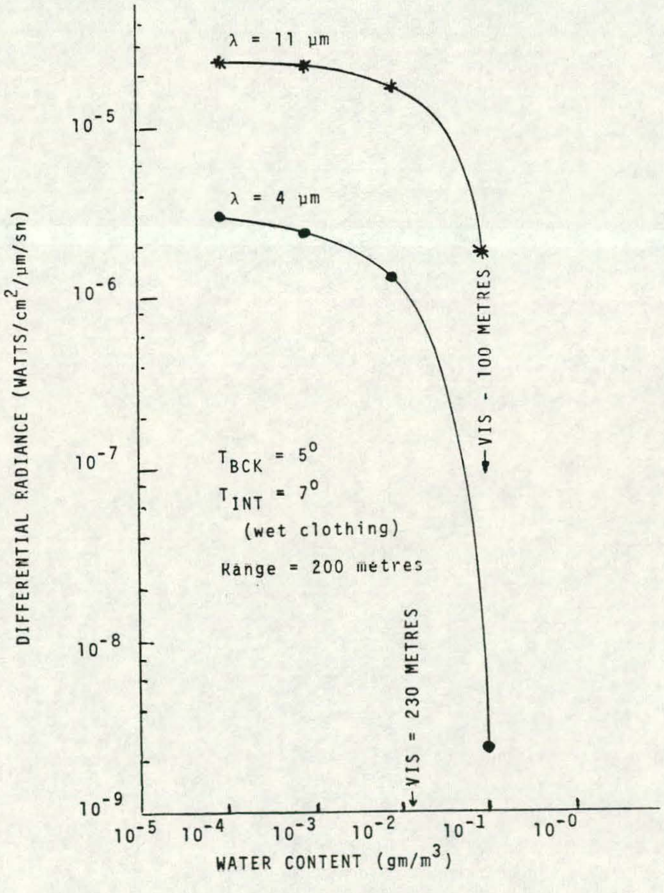
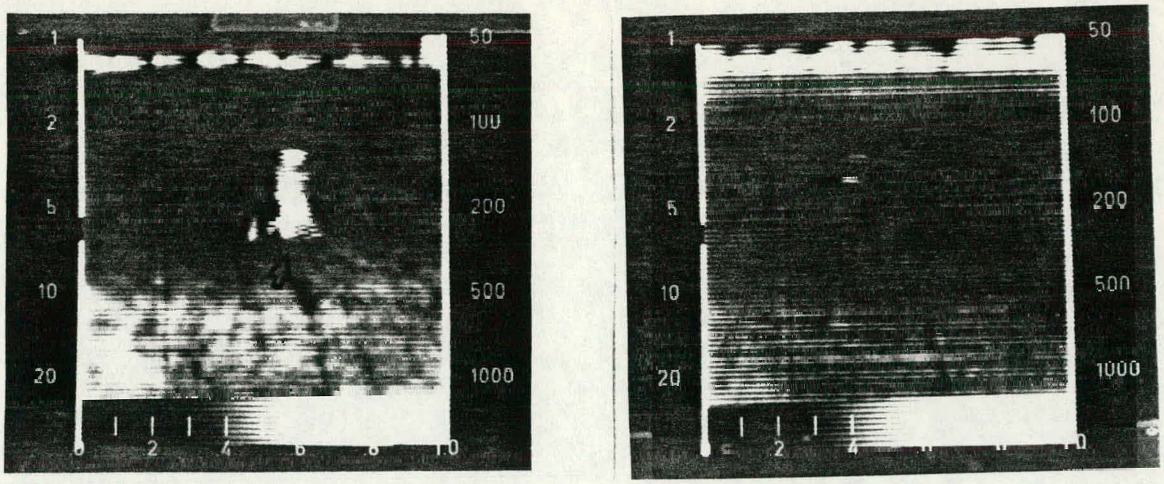


FIGURE 8. CONTRAST RADIANCE IN FOG AT TWO IR WAVELENGTHS



(a) DRY (b) WET

FIGURE 9. IR IMAGES OF AN INTRUDER CROSSING A GRASSY AREA

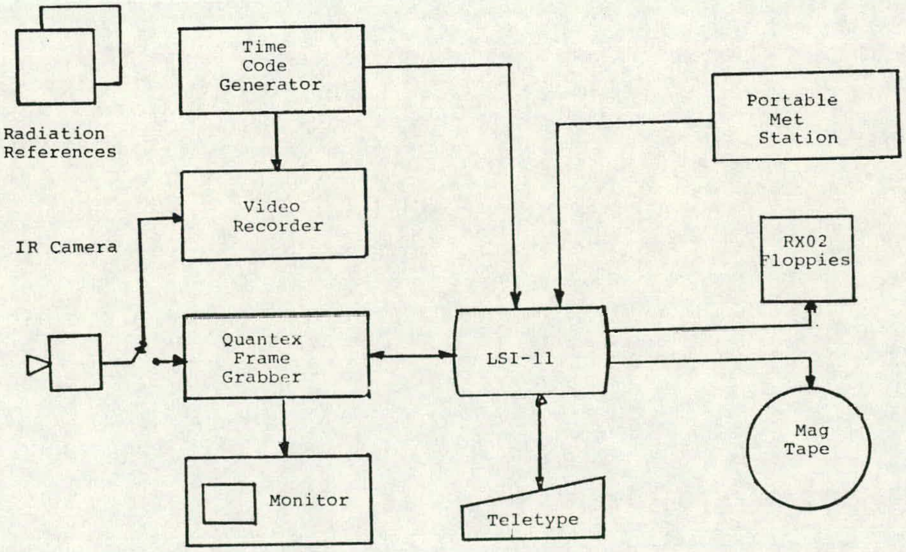


FIGURE 10. THE IR IMAGE ACQUISITION SYSTEM WITH SUPPORTING EQUIPMENT