Operational Testing and Applications of the AIRS FPA with Infrared Fisheye Optics

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ABSTRACT

Nova's development of the "Modular Infrared Imaging Applications Development System" (MIRIADS) produced a longwave infrared (LWIR) camera system that operated the "Adaptive Infrared Sensor" (AIRS) focal plane device produced by the Raytheon Infrared Operations (RIO) organization. A novel system architecture permitted the integration of an infrared fisheye lens system produced by Optics 1, Inc., which permitted a complete hemispherical field of view to be imaged onto the AIRS FPA. This paper will describe applications for this system as an extremely wide field-of-view IR sensor (early warning detection, fire detection, etc.), and will present test imagery collected with the system.

This technology advancement has been the result of the coordinated effort of a variety of companies and government agencies. This presentation will highlight significant contributions of individuals and will indicate the effectiveness of the Small Business Innovative Research (SBIR) program in helping to advance this nation's technology base.

FPA, LWIR, AIRS, electronics, dewar packaging, fisheye optics, sensor processing

1. INTRODUCTION

Under sponsorship from the Air Force Research Laboratory Munitions Directorate, Nova Research, Inc. has successfully completed the development of the MIRIADS system, an infrared camera system that has the capability to operate virtually all existing infrared focal plane arrays, with the additional capability to perform powerful real-time signal and image processing on the resulting image data. The great flexibility of the system architecture will speed the time required for existing FPA resources to be used in imaging tests, and the programmable nature of the signal processing system will permit a variety of mission-specific algorithms to be applied to the real-time digital data.

This paper presents an overview of initial imaging tests using the MIRIADS system with the AIRS FPA and the Optics 1 LWIR fisheye lens system. A variety of data has now been collected with this system and applications for this data will be discussed in this paper. Aircraft, automobiles, watercraft and other terrestrial data have been collected and a variety of system applications are under consideration.

2. DESCRIPTION OF THE AIRS/FISHEYE MIRIADS CAMERA SYSTEM

As pictured in Figure 2-1, the AIRS/Fisheye MIRIADS system may be used to collect a wide variety of LWIR imagery. The right inset of the figure shows the single-board "motherboard" that operates the FPA in its cryogenic dewar structure. In addition, the LWIR fisheye lens is mounted to the front of the dewar system with a focus mechanism. A variety of signal

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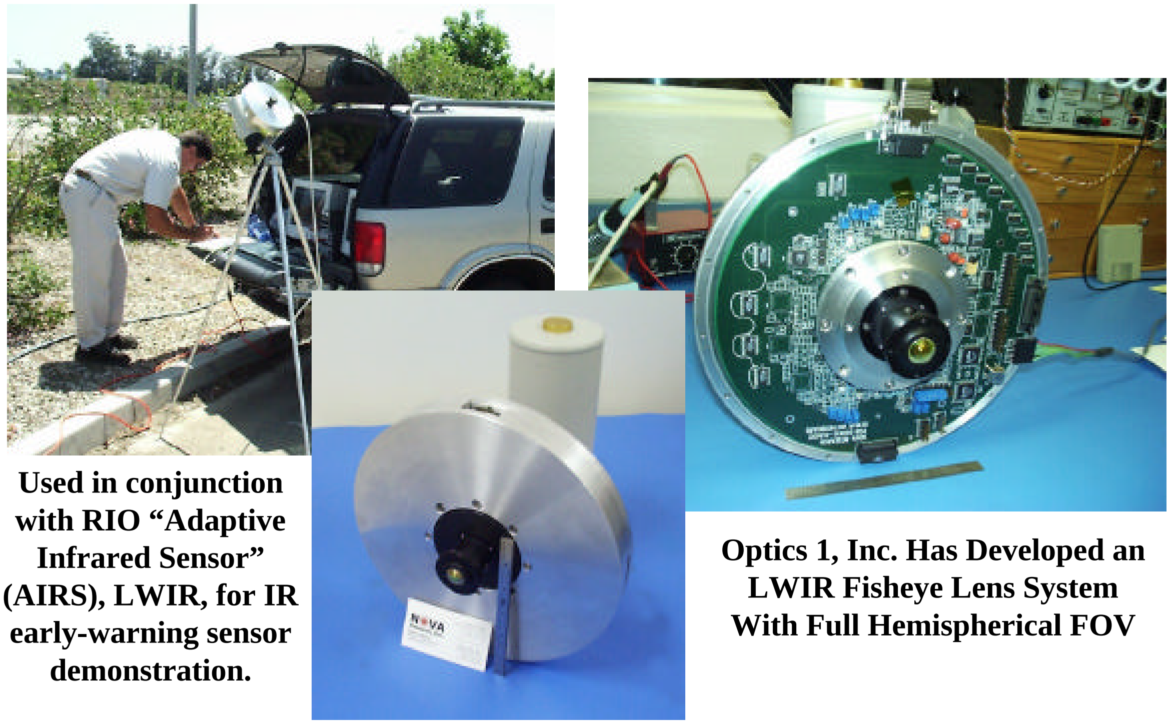
processing boards may be plugged onto the backside of the motherboard for application of special-purpose processing operations.



Used in conjunction with RIO "Adaptive Infrared Sensor" (AIRS), LWIR, for IR early-warning sensor demonstration.

Optics 1, Inc. Has Developed an LWIR Fisheye Lens System With Full Hemispherical FOV

Figure 2-1. An initial data collection effort provided a variety of aircraft and terrestrial data sets.

As pictured in the center inset, the combined weight of the MIRIADS camera head with its large-capacity LN_2 reservoir filled with LN_2 is approximately nine pounds. The large-capacity LN_2 reservoir may be replaced with a cryocooler for remote and/or airborne data collection purposes.

A design goal was to produce a system that provided an easy interface to a commercially-available image capture and display system so as not to divert from the main goal of producing a highly modular, configurable system. For this reason, the SE-IR Corporation's "CamIRa" display frame grabber, DSP board and software was identified and used to provide real-time display and digital data storage functions.

3. PRELIMINARY IMAGE DATA

Two-point Nonuniformity Correction (NUC) is a difficult operation with the fisheye-based system operating the AIRS in direct injection mode because the signal variation across the image plane is largely due to the spatial distortion of the lens. When the FPA's integration time is increased to improve the sensitivity of the system, the signal "bow" quickly fills the dynamic range of the sensor, resulting in saturation of pixels in the periphery of the fisheye's field of view.

The electronics on the DSP board of the SE-IR system were designed to perform NUC corrections based on signal variations that do not exceed approximately 50% of the instantaneous dynamic range (i.e. 50% of the input span of the A/D converter). Above approximately this value, the resulting NUC gains required exceed those supported by the NUC-processing hardware.

It is for this reason that the temporal highpass filtering (THPF) operating mode of the AIRS provides a great advantage when operating the system using the fisheye lens. In essence, the THPF processing will have the result of performing an "analog pre-corrected" offset correction on the FPA itself, thereby permitting the SE-IR DSP hardware to produce a high quality 2-point correction.

As a preliminary effort to visualize image frames from the LWIR fisheye system, sequences of frames were collected in the laboratory without application of real-time THPF or Subframe Averaging. Two-point nonuniformity corrections were applied using a software approach. A representative sequence is shown in Figure 3-1.

Figure 3-1.   Well-corrected frames subsampled from a 100-frame sequence, produced with application of a floating-point two-point NUC routine.

One might expect that applying a uniform blackbody illumination profile to a fisheye lens-based system is difficult. We found that a reasonably uniform illumination source was the hemispherical inside surface of a metal ice cream scoop that was spray-painted with flat black to produce a good, diffuse surface. One scoop was used at room temperature for the “cold” scene, and the other was dipped into a cup of boiling water, removed from the water and dried with a heat gun, then used to expose the sensor for the “hot” scene.

Total system noise was measured by computing the standard deviation of a group of 3300 pixels in a non-imaged portion of the AIRS FPA as indicated in Figure 3-2. Five separate data collection cycles were used to measure an average standard deviation of approximately 2.0 counts on a 14-bit scale (i.e., 2 counts out of a total dynamic range of 16,384 counts).

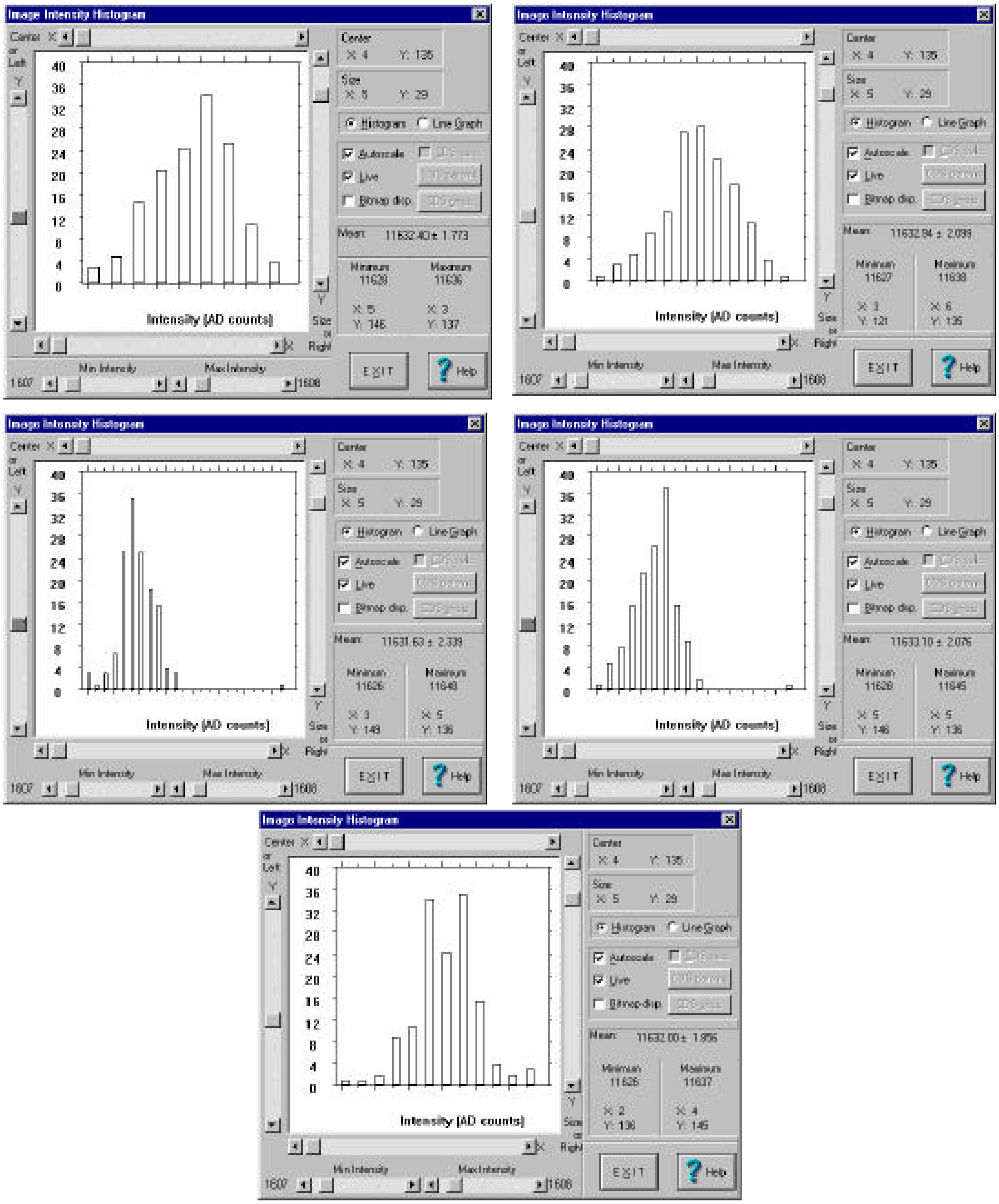


Figure 3-2. Five data histograms taken from a non-imaged portion of the AIRS FPA show an average standard deviation of approximately 2.0 counts on a 14-bit scale (16,384 total counts).

4. REAL-TIME TEMPORAL HIGHPASS FILTERING MODES

The AIRS has been designed to operate in three primary modes of operation. The first is a standard Direct Injection (DI) mode whereby the FPA operates as a standard 2D imager. A second mode of operation is Subframe Averaging. The advantage of this mode is that by averaging subframes, sensitivity is improved by reducing the effect of high energy photon shot noise. The third mode of operation, which we will focus on here, is Temporal Highpass Filtering (THPF). This mode is effective in reducing fixed pattern noise as well as the low frequency noise and drift components from the scene. The number of pixels operating with marginal performance is improved. As mentioned earlier, the THPF processing will in effect have the result of performing an "analog pre-corrected" offset correction on the FPA itself thus permitting the SE-IR DSP hardware to produce a high quality 2-point corrected image. Figure 4-1 shows six representative frames of a 100-frame sequence in which the nonlinear effects of fisheye-lens-induced illumination profile variations are compensated using this process.

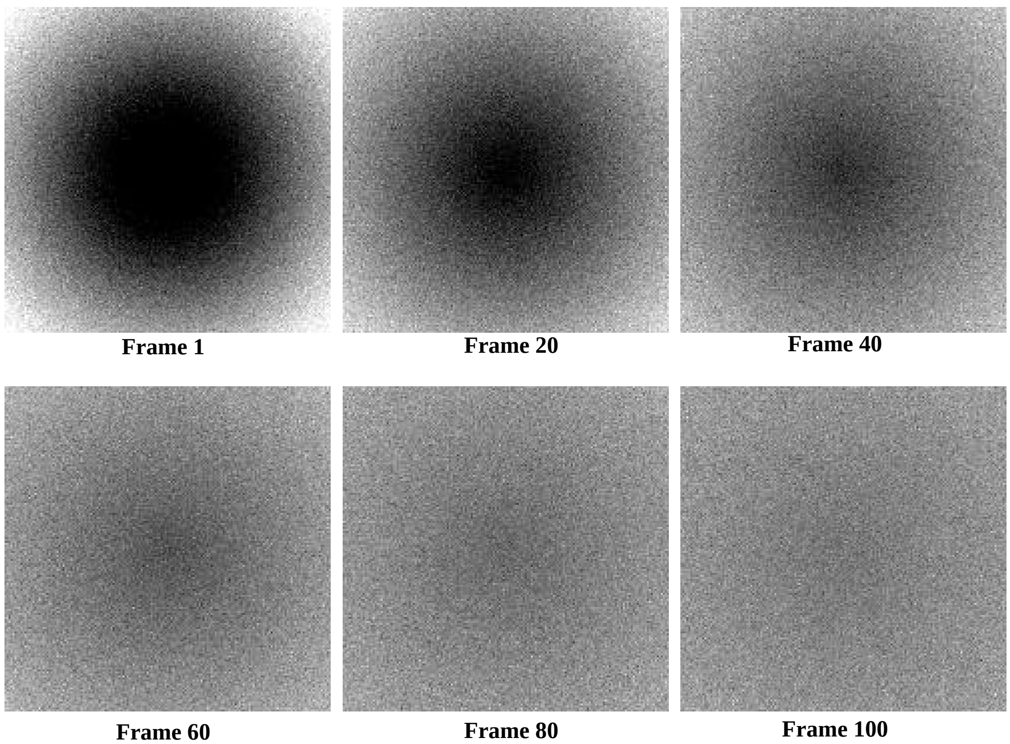


Figure 4-1. Fixed pattern image variation due to fisheye lens illumination profile is removed using a Temporal Highpass Filtering mode.

Frame 1 indicates the first frame in a representation of how the sensor would respond in a direct injection mode without the compensating effects of temporal highpass filtering. This is the first frame of a 100-frame sequence in which the THPF offset compensation is correcting (i.e., "flattening") the response of the sensor. Subsequent frames spaced at twenty-frame intervals are shown. Respective plots of even-numbered pixels in the 128th row (i.e., in the horizontal center row of each image) are given in Figure 4-2 for reference. The temporal noise incorporated in this example is representative of that achieved in the high background imaging condition (F/1.0) of the LWIR fisheye lens operated with the AIRS LWIR FPA. The detector operates in a lower noise condition when the illumination flux is lower, limited by an optical system having an F-number of approximately 2.3, presumably due to the higher dynamic resistance (RoA) of the detector at lower flux levels.

Applying temporal highpass filtering to real-time image data can provide a valuable tool for image tracking applications, at the expense of traditional image quality parameters. The upper three frames of Figure 4.3 present MIRIADS LWIR fisheye imagery with the AIRS FPA operating in its "Direct Injection" (DI) mode before application of any temporal highpass filtering. Notice that there are numerous fixed images in the three frames (overhead lighting and other laboratory thermal sources). The lower three frames of Figure 4-3 show the same three frames that have now been processed with AIRS-like temporal highpass filtering.

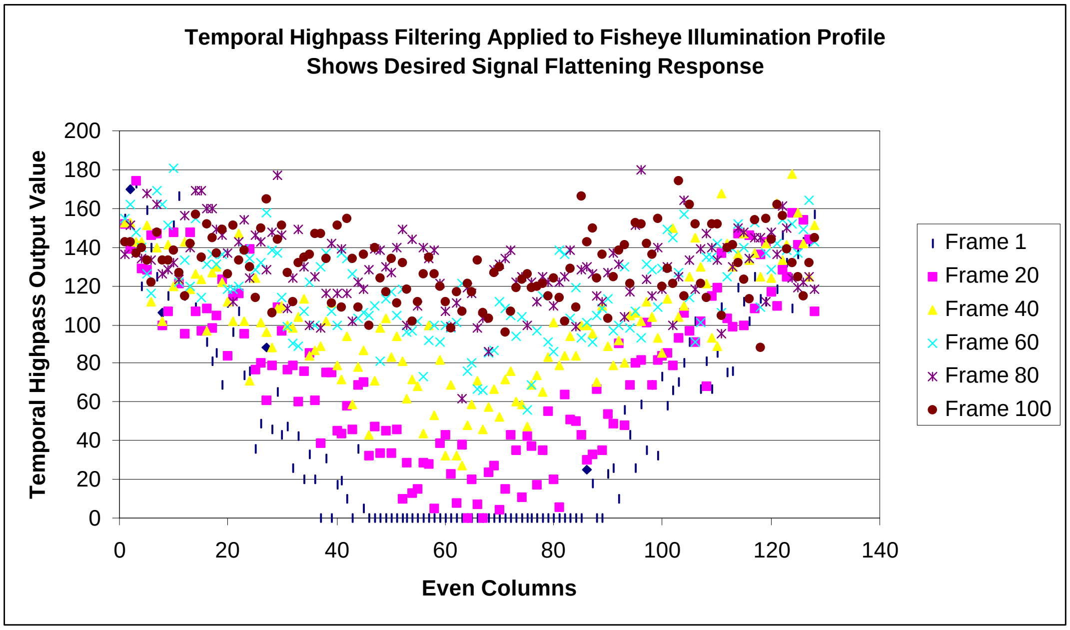
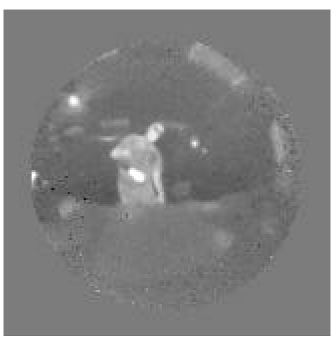
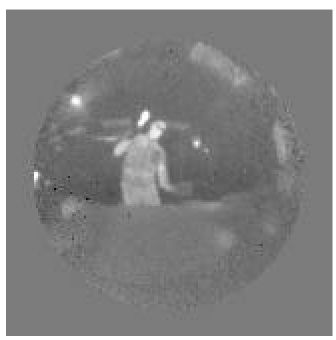


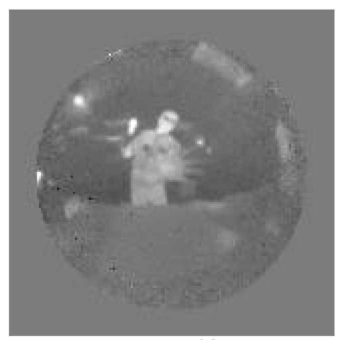
Figure 4-2. Image data corresponding to the images shown in Figure 4-1 indicate the rate at which fixed pattern image data is removed during THPF processing. Notice that the desired signal flattening behavior is shown, and that signal fluctuation due to temporal noise will pass through the process.



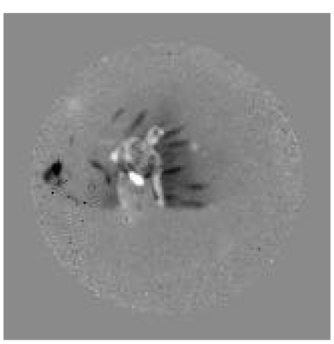
Frame 94



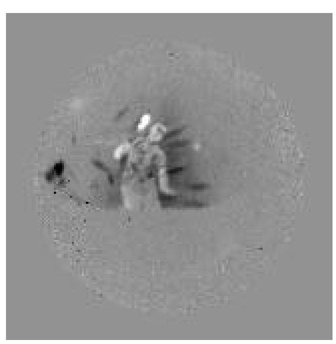
Frame 96



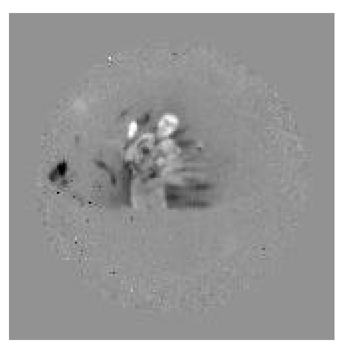
Frame 98



Frame 94 THPF



Frame 96 THPF



Frame 98 THPF

Figure 4-3. Application of Temporal Highpass Filtering to actual image data can provide useful target tracking information.

Some important aspects of the imagery in Figure 4-3 are worth noting:

- Spatial fixed pattern imagery has been reduced in intensity or completely removed. This is because only higher-speed objects will pass through the THPF process. You may see this by noting that the overhead lighting fixtures that were visible in the upper (input) frames have been erased in the lower frames.
- The moving person in the input frames remains in the lower frames by virtue of his motion.
- Bright sources will not only pass through to the output, but if bright enough, will produce a “latent” dark image that will fade away with time based on the temporal filtering adjustments provided by the AIRS FPA. While not useful from a conventional “image quality” sense, the ghost images record a time history of the motion of the objects, which could be of great use in target tracking applications. As an example of this, the particularly dark, large region in the lower left portion of the lower frames was produced because the soldering iron happened to dwell in this region for a reasonably long period of time before this particular image frames were recorded.

5. POTENTIAL APPLICATIONS

Wide Field of View Aircraft Sensor

Nova Research, Inc. has had a long and fruitful working relationship with Tanner Research, Inc., in which Nova has produced system-level infrared sensor hardware, and Tanner has developed a sensor processing algorithm, the Wave Process[1], designed to detect low contrast single-pixel moving objects immersed in cluttered backgrounds.

An extension to the development contract used to design and produce the MIRIADS system described in this paper is concentrating on a “real-time” application of Tanner’s Wave Process algorithm to live camera data produced by MIRIADS. In preparation for such high-speed processing, we collected through the fisheye lens a variety of data on flying aircraft, and applied the Wave Process off-line to the data to investigate the possibility of increased probability of detection for such low-contrast targets. These targets become unresolved “sub-pixel” targets when using the fisheye lens because the instantaneous field of view (IFOV) of a pixel subtends a relatively large solid angle, as compared to the case in which a conventional lens is used to image over a much narrower total field of view (TFOV).

Figure 5-1 shows three panels of frame clips. The left group of clips in each panel are individual frames from the 256 x 256 pixel AIRS FPA fisheye lens image. As the sequence proceeds, an aircraft takes off from left to right; without using some technique for improving the contrast of the aircraft with respect to background, it is very difficult to see the aircraft target.

The right group of clips in each panel are the respective Wave-Processed versions of these frames. Notice a characteristic chevron-shaped “wake” feature that is produced by the algorithm. The Wave Process improves the detectability of objects which move in a manner that is correlated in space and time by aggregating the detected signal over time, producing a wavefront with an amplitude that grows as the target is observed. Other moving objects in the field of view (e.g., people in the foreground in the right portion of the frame) will also produce such wave-like results and ongoing research at Tanner Research is concentrating on preferentially detecting objects of interest.

The Wave Process may be applied to a variety of applications in which the target contrast is low with respect to its background. Real-time application of this technique at Nova is through the use of MIRIADS-generated digital data interfaced to a SKY Computers, Inc. SKYsds-1 computer system. Numerous speed-enhancing operations have been incorporated into a modified version of the Wave Process; Nova expects to achieve a 30 frame/second processing speed of 128 x 128 pixel camera data. Similar results may be possible with other sensor types including sonar, LADAR imagers, UV, and passive millimeter wave imagers.

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[1] T.J. Bartolac, “Recent Developments in the Wave Process,” SPIE, Smart Focal Plane Arrays and Focal Plane Testing, Vol. 2474, April, 1995, pp. 40-50.

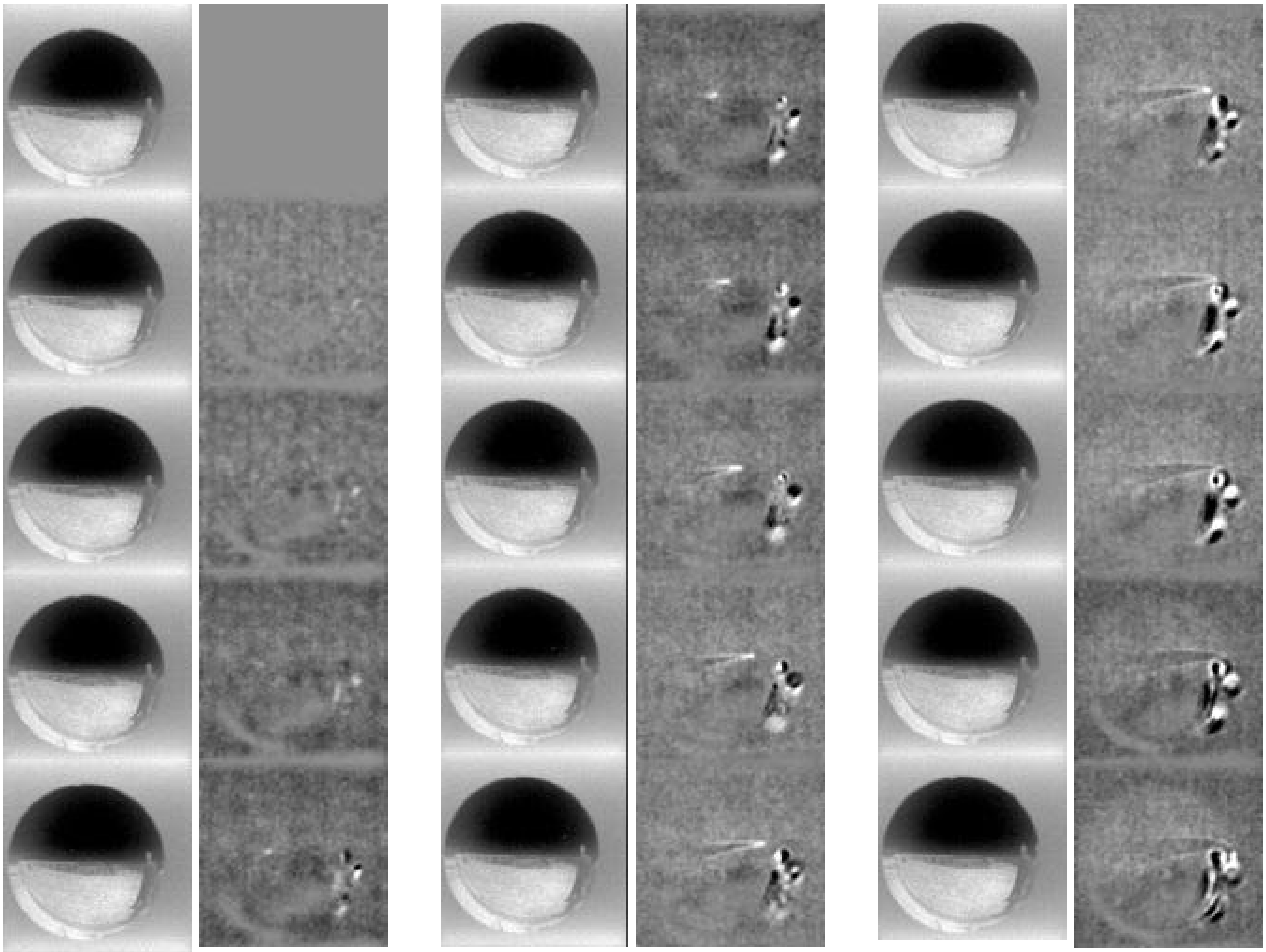

Figure 5-1. The AIRS/Fisheye MIRIADS was used to collect data on aircraft taking off (left panels in each group), and when the Wave Process was applied to this frame-based data the detectability of the aircraft is greatly improved.

Hemispherical Field of View Optical Fire Detector

We have investigated the possibility of using this hemispherical FOV system in a remote fire-detection application. For example, the 2π steradian field of view characteristic of the Optics 1 fisheye lens could be exploited to find the initial outbreak of open flames in a large convention hall. A single sensor located in the ceiling would have full coverage of an entire large indoor convention hall and the processing described below could be applied to the real-time sensor data to help identify the presence of the fire and provide the resulting information to fire control systems.

As a simple demonstration, a butane lighter was placed in the laboratory, and the AIRS/Fisheye MIRIADS system collected 256 frames of image data at a speed of approximately 7.0 frames/second, as shown in Figure 5-2. Higher frame rates are possible (up to the sensor's operational speed of approximately 60 frames/second).

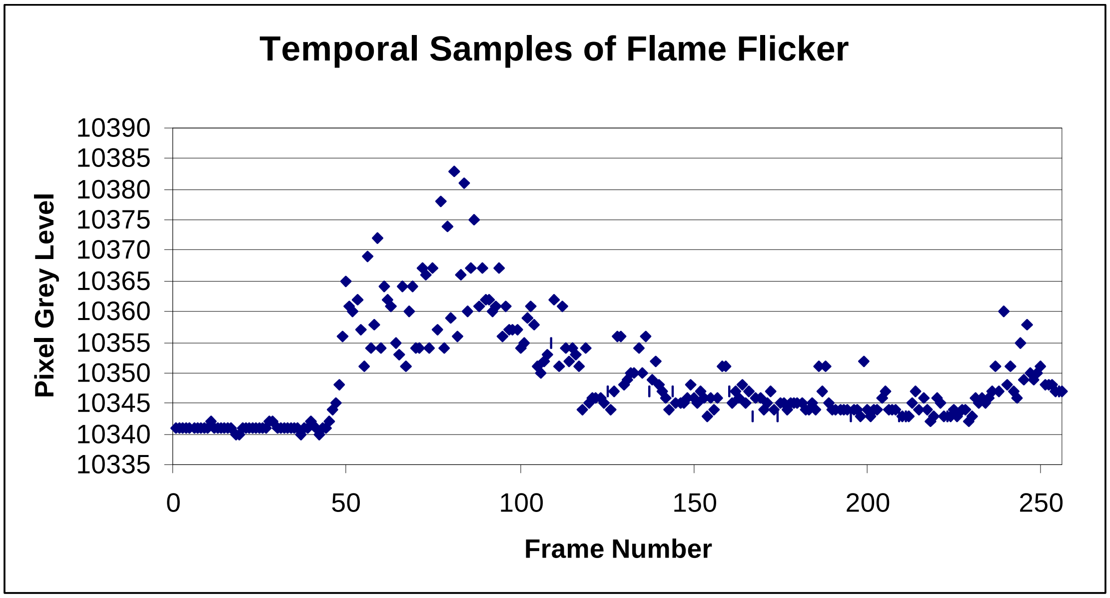

Figure 5-2. A single pixel in the LWIR image of a butane flame was monitored for 256 frames in preparation for application of an FFT to determine component flicker frequencies.

A simple data analysis routine was created that permits the user to specify a given pixel that is in the vicinity of the flame's time-varying image, and the 256 consecutive samples were recorded and subsequently analyzed using an FFT algorithm. Figure 5-3 shows the resulting characteristic frequencies of the flickering flame. This small dataset taken at a relatively slow sample rate produces a result that is band-limited (resulting in a false indication of the importance of higher frequency components), but the Power Spectral Density (PSD) plot in Figure 5-4 gives a reasonably good indication of the importance of such relative spectral powers.

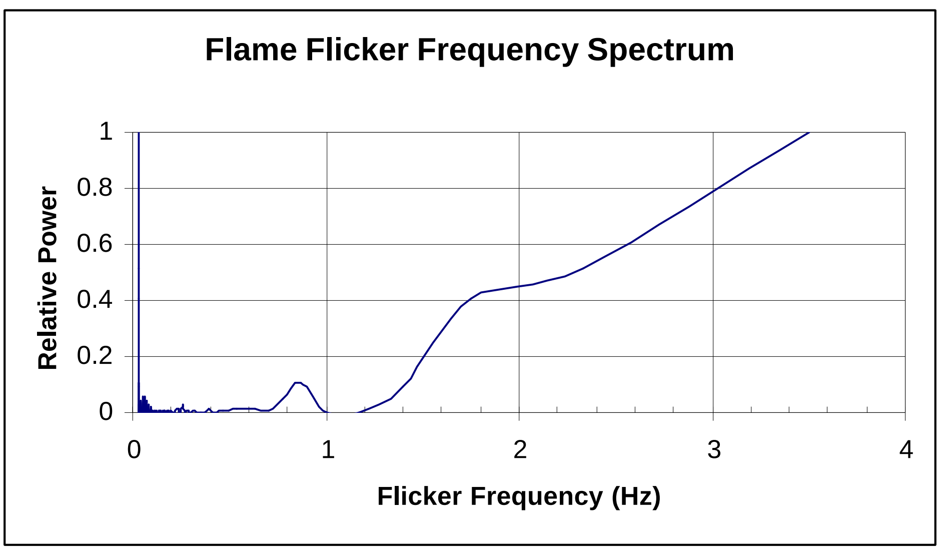

Figure 5-3. Disk I/O overhead in this data collection was limited to recording at 7 frames/second. This resulting frequency spectrum was produced, showing a characteristic flicker peak at approximately 0.87 Hz.

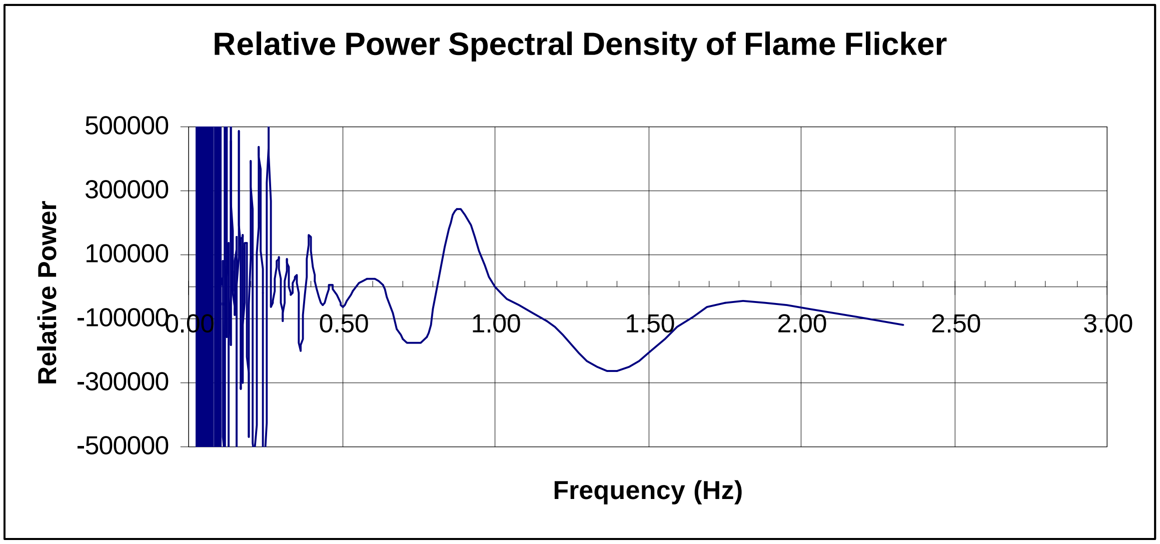

Figure 5-4. Relative Power Spectral Densities of flame flicker indicates a characteristic flicker frequency at 0.87 Hz.

In future commercial applications, the MIRIADS system could be configured to compute a real-time FFT similar to the result shown above, and compare characteristic frequencies with known spectral distribution signatures of actual fires. In so doing, the goal would be to reduce the false alarm rate while operating the system with full FOV coverage. An important advantage of this system would be to communicate this information to fire extinguishing systems that would apply fire retardant to only specific regions in the protected zone such that sensitive equipment in non-fire areas would not suffer potentially damaging application of water or foam.

6. ACKNOWLEDGEMENTS

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