Abstract - Infrared, image intensified, and low light level CCD sensors have well recognized uses, capabilities and limitations. Several government and industry studies objectively evaluated the relative merits of these sensors as applied to the day and night pilotage missions. These studies found that each sensor excelled under different conditions and environments. Most pilots preferred having at least two different types of sensors available, since they sometimes complement each other.

The ultimate goal of image fusion is to provide an automated method integrating the various image information from different sensors to yield a high quality real-time presentation. Ideally, such a composite should retain the essential information from each sensor while minimizing any artifacts or distortions so that the end result is a seamless representation of reality. By putting together several technologies, image fusion offers an overall improved single image representation of thermal, visible and color, etc.

Raytheon has developed image fusion algorithms for fusing high sensitivity/resolution sensors for both the long-wave infrared (LWIR) and the visible-near infrared (V/NIR) spectral regions. The algorithms are implemented in real time processing hardware and have been demonstrated in various aircraft, including helicopters. The imagery from the two respective spectral bands is fused via digital image processing techniques such that the information content is optimized for a variety of daytime and nighttime scenes. Imagery from these demonstrations shows dramatic improvement in situational awareness for pilotage.

Keywords: Image fusion, local area processing (LAP™), FLIR, image intensified TV, image processing.

1 Introduction

There is a need for improved situational awareness for pilots operating aircraft at night. Some military air missions require extended aircraft operations in close proximity to the ground, e.g., tactical helicopters and search and rescue aircraft. Civilian needs include night search and rescue as well as general aviation night-time operations close to the ground.

In recent years, infrared sensors and low light level visible band sensors have achieved greatly improved sensitivity and resolution. These sensors have also benefitted from greatly improved digital electronics, which enable greater sensitivity and resolution, lower weight, volume, power, and cost.

Government and industry studies have objectively evaluated the relative merits of these sensors as applied to the day and night pilotage missions. These studies found that each sensor excelled under different conditions and environments. Because of environmental variability and limitations of each type of sensor operating by itself, most pilots preferred having at least two different types of sensors available, since they sometimes complement each other.

The goal of image fusion is to provide an automated method integrating the various image information from different sensors to yield a high quality real-time presentation. Ideally, such a composite should retain the essential information from each sensor while minimizing artifacts or distortions such that the end result is a seamless representation of reality. By putting together several technologies, image fusion offers an overall improved single image representation of thermal and visible scene content.

This paper describes Raytheon’s work in image fusion algorithms for fusing long-wave infrared (LWIR) and the visible-near infrared (V/NIR) spectral regions. The algorithms are implemented in real time processing hardware and have been demonstrated in various aircraft, including helicopters. The resulting imagery provides a dramatic increase in situational awareness for pilotage.

Section 2 discusses characteristics and limitations of both FLIR and IITV sensors. Section 3 presents a brief history of image fusion development at Raytheon. Section 4 discusses sensor fusion architecture. Section 5 presents the results of real time implementations. Section 6 presents flight test results, and Section 7 presents conclusions.
2 Single Sensor Characteristics and Limitations

Both FLIR and IITV imaging sensors detect unique characteristics of the scene. A FLIR sensor operating in the infrared band (e.g., MWIR at 3-5 micron and LWIR at 8-12 micron) depends on the emissive characteristics of the objects in the scene. The sensor detects temperature differences of the various objects. Extremely sensitive FLIRs, can detect temperature differences of less than 0.01 degrees Centigrade. FLIR performance is independent of ambient lighting; however, environmental conditions such as diurnal thermal cross-over may cause the scene to have very little thermal contrast such that the FLIR image is very poor.

An IITV sensor, on the other hand, relies on scene reflective characteristics and light sources. A high performance IITV sensor can operate in light levels as low as 3x10^-6 foot Lambert. IITV performance is unaffected by poor thermal contrast conditions; however, environmental conditions, such as heavy cloud cover, may cause ambient lighting to be so low that image quality is degraded. Bright lights in the scene may also cause pixel saturation and blooming.

3 Development History

In the 1980's, the U.S. Army's CECOM Night Vision and Electronic Sensors Directorate and industry began an extensive evaluation of the relative merits of night vision goggles and thermal imaging. These studies are typified in report NV-1-301. The findings of this report included the results of surveys of pilots' preferences for goggles and FLIR.

4 Image Fusion Architecture

The primary goal of image fusion architecture is to dynamically combine various image information from multiple registered image sources at the pixel level to yield a high quality composite real-time presentation for operator viewing.

To accomplish this goal, it is necessary for the processing to be tightly coupled with the individual sensors. Care is taken to register, optimize, and normalize the individual sensor videos prior to the fusion process. Resultant sensor signal to noise ratios and other image quality metrics are estimated as a function of individual sensor gains and post processing statistics.

The fusion kernel function, which performs the core image fusion algorithms, receives distortion corrected FLIR video and enhanced IITV video. (One could also perform distortion correction on the IITV video, rather than the FLIR video.) The local area processing separates each video signal into feature and background components, based on local area criteria. The feature component of the video is a function of the local area contrast and contains the primary scene details. The background is representative of overall scene level and broad area shading. The fusion kernel further processes these components based on spatial, temporal, and sensor signal to noise characteristics. It then combines features

In early 1989, Raytheon developed and patented an image fusion method, based on local area processing techniques, which provides very good results. This approach involves pixel level, computationally intensive, techniques. The pixel level computations do not lend themselves to implementation in general purpose processors or mission controllers. Consequently, the hardware developed uses an algorithm specific architecture which is configured under software control. Approximately 1000 operations per pixel are required to implement the image fusion algorithms.

Initial image fusion flight testing took place as part of the Superteam's Light Helicopter Experimental (LHX) Demonstration/Validation program on the AV05 evaluation helicopter. Although this industry team was not successful in its bid for the Comanche program, Army pilots who flew image fusion gave it high marks and Raytheon was encouraged to continue work on the concept.

Army interest in an image fusion evaluation developed through a series of flight demonstrations at Ft. Rucker, St. Louis and Ft. Belvoir. An unsolicited proposal was submitted to AATD and NVESD. In 1991 AATD and NVESD agreed to jointly conduct an assessment of Raytheon image fusion to determine its value as a pilotage aid for night-time low level flight.

The success of the above image fusion evaluation led to including fusion in the AHP (Advance Helicopter Pilotage) and DARPA FIS (Fused Integrated Sensor) contract awards in 1996. Fusion in the AHP system comprehended the high resolution sensors (1600 pixels by 960 lines), which quadrupled the circuits from the earlier fusion configuration, and backgrounds from each sensor in a way that maximizes detail in the resultant fused image while minimizing noise and undesirable sensors artifacts such as “ion sparkle” and blooming in the IITV video. Figure 1 is a top level block diagram of the fusion process.

Figure 2 illustrates how information from infrared and visible wavelength images often provide complementary information for a typical pilotage scene. Note that the FLIR image has much of the scene definition, and the IITV image alone is not very useful; however, the IITV provides horizon definition, additional building detail, and lights. In the fused image, the IITV blooming lights are replaced with modified, non-blooming lights. The resulting composite image contains the most useful information from each sensor.

It should be noted that an unsophisticated algorithm, such as summing the FLIR and IITV video signals, is not sufficient because objects (e.g., wires and structures) may have opposite polarity in the two images and would not be present in the composite video. This would be disastrous for night-time low level flight.
5 Real-time Implementation

While image fusion is a simple concept, it is a challenge to implement in such a manner that the full benefits are realized without introducing unwanted artifacts in the imagery. Also, the high video data rates and low display latency (delay time) requirements make real-time implementation a significant issue. Raytheon has successfully worked these problems on several previous programs, including the Image Fusion Evaluation Program (AATD) and Advanced Helicopter Pilotage Program (AHP). The basic functions of image fusion are illustrated in Figure 1, and are described below.

**Video Interface** - This function (not shown in Figure 1) accepts the input video from the sensors to be fused, and provides fused output video and several other video output options for diagnostic and evaluation purposes. Multiple output channels are available to allow comparison of raw input, pre-processed input, and fused output video. External sync signals to align one sensor video timing to the other sensor.

**Distortion Correction** - This function adjusts pixel locations on one of the sensors to align with those of the other sensor. Mis-registration can occur because of distortion differences, boresight errors, and magnification differences.

**IITV Image Enhancement** - This function is applied to the IITV output, to improve contrast and reduce impulse-type noise characteristic of these devices.

**Local-Area Processing** - LAP performs the functions of AGC (automatic gain/level control) and image enhancement. LAP filters the scene into low-frequency (background) and high-frequency (feature) components, then compresses the low-information background pedestals, while enhancing the feature content. Figure 3 illustrates the effect of LAP. LAP can be used in standalone applications requiring AGC and dynamic range compression.

**Feature Processing** - This function processes the feature signal from LAP to generate an “energy window” signal. This signal is used to generate selection metrics.

**Feature Selection** - This function computes metrics to determine the appropriate combination of video from the individual sensors to be used in the final fused image. Several criteria are employed, including local area statistics, intensity, and past history.
6 Flight test results

The primary goal of data evaluation flight tests were to evaluate the pilotage utility of the fusion system under a wide range of carefully documented environmental conditions. The flight test conditions encompassed a representative range of thermal, lighting and environmental conditions corresponding to varying image conditions for the FLIR and IITV sensors.

The environmental aspect of the flight tests was to test image fusion over enough different environmental conditions to produce a set of FLIR and IITV conditions ranging from good to poor. Certain environmental parameters are tied to sensor conditions. These parameters are thermal temperature difference (foliage and ground) and illumination level. Based on the historical data collected in previous night vision sensor experiments, a matrix of system conditions desired and the corresponding light level and delta-T conditions was developed. This matrix is shown below in Table 1 with the number of evaluation flights accomplished in each set of conditions. The goal of completing the matrix with all four pilots under each condition was not accomplished due to the difficulty in obtaining all combinations of conditions. However, this was deemed sufficient since the range of conditions tested, covered the extremes for each individual sensor and no anomalies were found in the results.

Table 1 Sensor Environmental Condition Matrix

<table>
<thead>
<tr>
<th>ILLUMINATION</th>
<th>FLIR DELTA - T</th>
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<tbody>
<tr>
<td>HIGH</td>
<td>MODERATE</td>
</tr>
<tr>
<td>&gt;1.5 DEG. C</td>
<td>0.5-1.5 DEG. C</td>
</tr>
<tr>
<td>FULL MOON</td>
<td>4x10^{-3} – 3x10^{-2} fc</td>
</tr>
<tr>
<td>1/4 MOON</td>
<td>9x10^{-4} – 4x10^{-3} fc</td>
</tr>
<tr>
<td>NO MOON</td>
<td>&lt;7x10^{-5} – 9x10^{-4} fc</td>
</tr>
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</table>

Flight test results include the pilot ratings from the formal data flights, the guest evaluator ratings from the excursion flights and the recorded imagery and flight data. After each flight was completed, the evaluation pilot completed a six page questionnaire, answering detailed questions regarding his performance with each of the sensor configurations. Questions covered such areas as workload, confidence, dependence on symbology, etc. The questionnaire ended with a rating sheet in which the pilot was required to provide twelve different ratings in four separate categories. The pilot was asked to rate each sensor configuration from 1 to 3, with 3 being the best. Additionally, he could use a plus rating (2+, etc.) for further discrimination. Table 2 summarizes the average ratings in each category for all of the flights. Also, included in the table is a standard deviation metric which is indicative of the amount of variance in the rating over all of the conditions.
The FLIR and IITV ratings were between 1 and 2 depending on the conditions. The average FLIR and IITV ratings were very close in the NOE/Contour category. In this category, the pilots saw significantly varied terrain. However, the Hover task was always repeated in the same location and tended to have a foreground area which had poor visible contrast. It is presumed this accounts for the FLIR having a slightly better average rating than the IITV in Hover categories. The Fused rating was near 3.0 in all categories indicating that it was the preferred configuration for all conditions tested. Figure 5 shows a graphical representation of the ratings in each category. It is also instructive to look at the ratings of the individual sensor configurations versus the environmental conditions under which they were rated. Figures 6, 7, and 8, respectively, show the ratings of FLIR, IITV and Fused configurations.
As can be seen from Figure 6, the FLIR rating varies between 1 and 2. The rating tends to increase with improving thermal conditions and decreasing illumination conditions. From Figure 7, the IITV rating also varies between 1 and 2. The IITV rating improves with increasing illumination and decreasing thermal conditions. From Figure 8, the fused rating was consistently near 3 and was independent of varying environmental conditions.

Additional data and information supported pilot rating during each flight. Video tape recordings of each flight with all three sensor configurations were reviewed at the conclusion of each flight. These video recordings contained an audio track with the pilot, safety pilot and flight engineers comments. Additionally symbology was overlaid on the recorded video with aircraft attitude and other flight parameter information. The safety pilot on each flight also completed a questionnaire regarding the subject pilot’s performance in each of the sensor modes. Generally, the safety pilot’s assessment of the subject pilot’s performance tracked very well with the subject pilot’s assessment of his own performance. Recorded video also substantiated the subject pilot’s assessment with the recorded airspeed and altitude being key parameters.

Figure 9 shows another example of FLIR, IITV and fused images from the real-time fusion tests discussed above.

7 Conclusions
Both FLIR and IITV sensors are used for night-time pilotage. Fusing the scene emissive characteristics sensed by a FLIR sensor and the scene reflective characteristics and light sources sensed by an IITV sensor provides a composite image which is generally superior for night-time pilotage of aircraft operating in close proximity to the ground. Real time implementation of fusion algorithms and helicopter flight tests show that pilots have greatly improved situational awareness when flying with fused imagery from FLIR and IITV sensors. Results from the flight tests showed that pilots have a strong preference for the fused image display versus either FLIR or IITV alone. Miniaturized digital electronics enable single board implementation of image fusion for airborne, ground vehicle, or personnel sensors.

8 References


2. R. Vollmerhausen, C. Nash, Design Criteria for Helicopter Night Pilotage Sensors, NVESD.

3. T. Bui, B. Gillespie, Night Pilotage Sensors Field Assessment, NVESD.


