Radar E-O Image Fusion

William F. O'Neil
Westinghouse Electric Corporation

Abstract

The fusion of radar and electro-optic (E-O) sensor images presents unique challenges. The two sensors measure different properties of the real three-dimensional (3-D) world. Forming the sensor outputs into a common format does not mask these differences. In this paper, the conditions under which fusion of the two sensor signals is possible are explored. The program currently planned to investigate this problem is briefly discussed.

Introduction

Westinghouse has been developing novel adverse weather landing aids for commercial and military aircraft. We have concluded that it will be necessary to use a multiple sensor suite to provide both an active radar imaging sensor, and a passive imaging E-O sensor. The radar imager provides excellent penetration of adverse weather, but has limited angular resolution. The E-O sensor provides very good angular resolution but is severely affected by adverse weather such as fog, rain or snow. The fundamental property that distinguishes the two sensor classes is operating wavelength. This is both the driver on adverse weather penetration, and the driver on angular resolution. When the wavelength is greater than the size of atmospheric aerosols and raindrops, the penetration is good. When the wavelength is small compared to the receiving aperture, the resolution is good.

For the current paper, an equally important distinction is the difference between active sensing and passive sensing. An active sensor provides its own illumination of the scene to be imaged, while a passive sensor depends on either some external illuminator, or on self-emitted radiation of the objects being imaged. An active sensor has an advantage in that the properties of the illuminating waveform can be exploited for coherent detection of reflected energy. This dependence on reflected (i.e. back scattered) energy determines how the active sensor images a real 3-D scene. Specifically, electromagnetic properties that are determined by the surface to some depth are important in determining the reflection characteristics. In addition, macroscopic scale features are important since energy can experience multiple reflections before being returned to the receiver.

For the E-O sensor the considerations are very different. Few surfaces are optically smooth. Thus the behavior of such surfaces in reflected light is significantly different than the behavior of the self-emitted energy. Multiple reflections of emitted or reflected energy play a minimal role in determining signal. The properties that determine reflection or absorption are not well correlated with the bulk properties that determine reflection and absorption at radar wavelengths.

The third distinction between radar and E-O sensors is that different evolutionary paths have resulted in radar providing very precise range and range rate measurements with only limited emphasis on received signal strength which is the only property usually quantified with an E-O sensor. For the application at hand, the radar image is returned as a range versus azimuth angle using an antenna that is mechanically scanned, and which has a shaped beam pattern designed to minimize the variation of signal with elevation angle, under the assumption of flight nearly parallel to the ground where returns originate. The use of range versus angle as opposed to signal return level versus angle presents some challenges. Height of a return source above terrain is lost. Converting from an azimuth/range/intensity image to an azimuth/elevation/intensity image requires an assumption about the height of the return sources. Figure 1 shows an E-O sensor image of a runway at the Salsbury MD airport. Figure 2 shows the same runway as viewed using an X-Band (10 GHz) radar operated in the Monopulse Ground Map (MGM) mode. Figure 2 was derived from Figure 3 (azimuth/range/intensity) by assuming that all reflecting elements are in a ground plane which has a known orientation with respect to the flight path. As shown in Figure 4, each range cell in the radar return is assigned an elevation angle on the basis of the aircraft height above the ground plane. While there are a number of important error sources which must be accounted for in this process, for the purpose of this paper, it is sufficient to assume that those difficulties will be overcome, and that a proper image in angle/angle/intensity format will be achieved.

Fusion Technique

Westinghouse has approached the task of Radar E-O image fusion as an evolution of previously developed technology. The MGM mode for the radar, coupled with a transformation from azimuth/range to azimuth/elevation produces an image which has a compatible format with standard E-O images and displays. Westinghouse has also been participating with the David Sarnoff Research Center in a program that uses pyramid decomposition of visible and IR E-O images to construct fused images. That program has advanced to the point where real time operation at television rates and resolutions will be possible in the very near future. Combining these two developments provides a path to the desired Radar E-O fusion. The paper by Dr. Hannah at this workshop describes the pyramid fusion technique for visible and IR images. The interested reader will find additional information in references 1-3.

Figure 5 shows the general arrangement of a postulated Radar E-O image fusion system. The Radar is operated in the MGM mode and creates angle/range/intensity images at a low frame rate. These are converted to angle/angle/intensity images using a combination of on-board inertial and altitude sensors. The images are used to generate a 30 Hz image stream by motion compensation plus image extrapolation. This step may occur either before or after pyramid decomposition, depending on engineering details. The Radar images are decomposed using pyramid decomposition. The E-O images are similarly decomposed, so that features from both images can be identified, matched, and registered. Feature blending/selection is used to produce the composite image in transform space. This image is then inverse transformed, using the merged pyramids to construct the angle/angle/intensity image. Standard processes, such as gain and level adjustment, are then used to correct that image prior to display.

The pyramid decomposition has the effect of generating intermediate images which contain a limited range of spatial frequencies. Thus, the decomposition of a high resolution E-O image will result in transformed images that have resolution compatible with the Radar resolution. By suitable choice of scan angles, sampling rates, and optical design, the reduced resolution image will match the resolution of the Radar such that direct comparison and fusion of features will be possible. Figure 6 shows the decomposition and feature match processes. The fusion process, represented by a single block, is a variant of the previously published work.

Each cycle of the pyramid decomposition produces a bandpass image (the Laplacian) that contains one octave of spatial frequency data, plus a residue image that contains all spatial frequencies from zero to the lower limit of the bandpass image. The two image sources can, by suitable choice of sampling grids, provide bandpass images that share a common range of spatial frequencies. It is also a property of the pyramid decomposition process that the spatial coordinates of each feature are preserved in the transform process. Thus, each feature will be represented by both spatial coordinates and spatial frequency content. Relatively simple operations such as rectification and threshholding permit the determination that the feature is present. If such a test is satisfied in both images, then the features can be fused into a single feature that can be displayed. In addition, a feature present in one image, but not the other, can be used in the composite image. This will provide an image containing the information from both sources.

Fusion Issues

The above discussion of Radar E-O fusion has glossed over several potential difficulties. The most obvious is commensurability. Are the features in a Radar image sufficiently similar in size, shape, location, or intensity to be clearly identifiable as the same feature by some analytic rule? Is the only answer to this question anecdotal, or is there a formal method for resolving this issue?

One approach to the commensurability is shown in Figure 7. Both scenes are derived from the same 3-D real world. Each of the sensors has performed a transform into one or more spaces depending on where we choose to view the image. If we can add a transform to one or both images which produces intermediate images which are demonstrably the same for equal real world inputs, then, in that transform space, they are commensurable and can be merged. As inspection of Figure 7 shows, it is a generalization of Figure 5 which is the particular transform path we are exploring.

Another issue might be called "fusability". If we identify a feature from both sensors, and can conclude that it is the same feature, we are still left with the need to transform the features in such a way as to provide commensurability in intensity space. We have not envisioned an alternative since the objective is to provide an intensity/angle/angle image for a pilot. The fusability issue is also linked with the issue of deciding which sensor contributes how much to the final image. The visible IR fusion effort used a binary decision rule, but we anticipate that a blending rule will prove advantageous in the present case. Some departure from current radar practice may be needed to assess the image quality of the radar signal, and assign the transformed image an equivalent intensity for a blending rule.

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Still another issue of concern is the subject of clutter. Spatial clutter is a potential problem for both sensors, while temporal clutter is observed in Radar images. Such clutter complicates the processing task, since it represents additional features which must be analyzed. Applying image extrapolation to achieve compatibility with the 30 Hz video, may aggravate clutter as a distraction to the pilot. The low sample rate which is provided by the radar is effectively aliased into higher temporal frequencies by any extrapolation algorithm.

Current Plans

Westinghouse is engaged in an analytic and experimental program to investigate these issues. The analytic program includes development of basic theoretical models for the sensor phenomenology, as well as investigations using simultaneous data from multiple sensors. To address these issues requires that a significant data base be available. Westinghouse has an instrumented aircraft that provides both radar and E-O sensors with digital data collection. Initial efforts will include collecting data from the Westinghouse MODARS weather radar together with visible and IR E-O data. This will be processed in our image processing laboratory to evaluate algorithms and assess fundamental problems which must be solved. From these results, we plan to formulate a program where the fusion process can be implemented as a real time airborne process.

Conclusions

The fusion of Radar and E-O sensor data will provide the ability to select an optimum mix of resolution and penetration for each weather condition that will be encountered. To be effective, the fundamentals of fusion across different image domains must be established so that a fully automated fusion system can be implemented. The spatially coherent pyramid decomposition technique appears to offer significant benefits in this fusion effort. There are fundamental unanswered questions which must be addressed. In addition, the experimental data base required to assess alternative theories has not been obtained. Westinghouse has initiated a program that will address the theoretical and experimental issues of Radar E-O fusion.

References:

1. Burt, Peter J. and Edward H. Adelson, "Merging Images Through Pattern Decomposition", SPIE National Summer Conference, San Diego, CA Aug. 18-23, 1985

2. Burt, Peter J. and Edward H. Adelson, "The Laplacian Pyramid as a Compact Image Code", IEEE Transaction on Communications, Vol COM-31, No. 4, April 1983

3. Pavel, Misha and James Larimer, Editors, Session 25 of the Society for Information Display Meeting of May 20, 1992 contains three papers on image fusion.

Figure 1 Visible Sensor Image of Runway and Environs
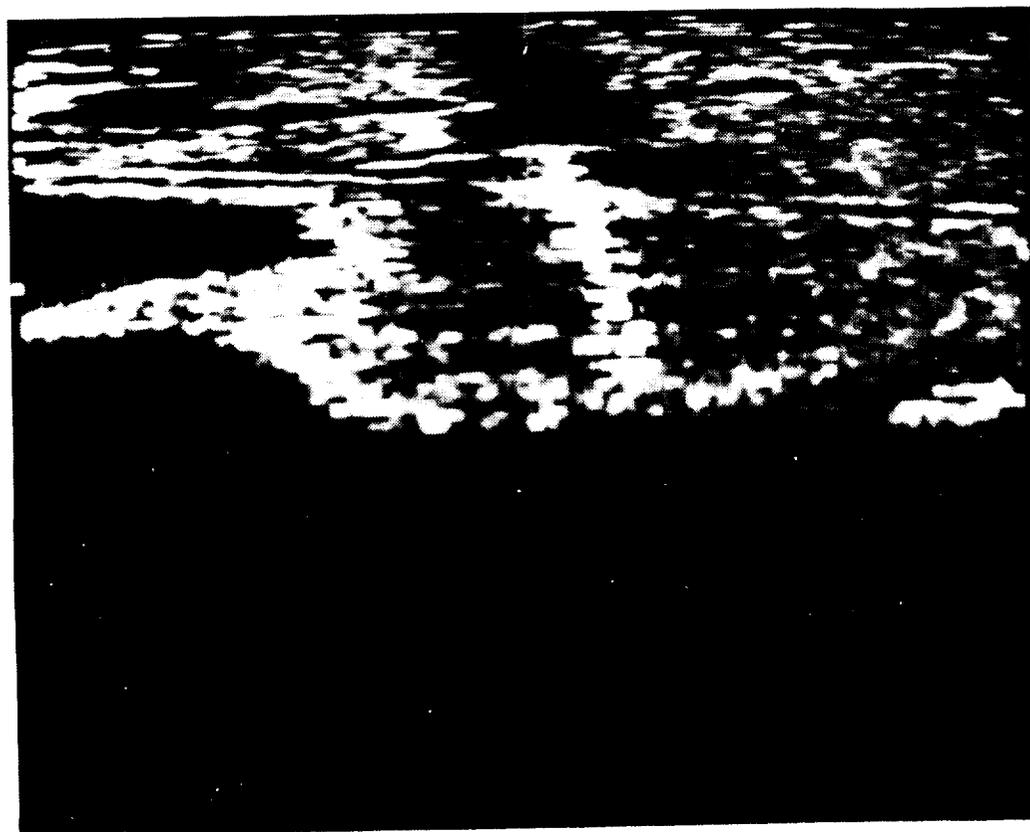
Figure 2 Angle/Angle Radar Image of Runway and Environs
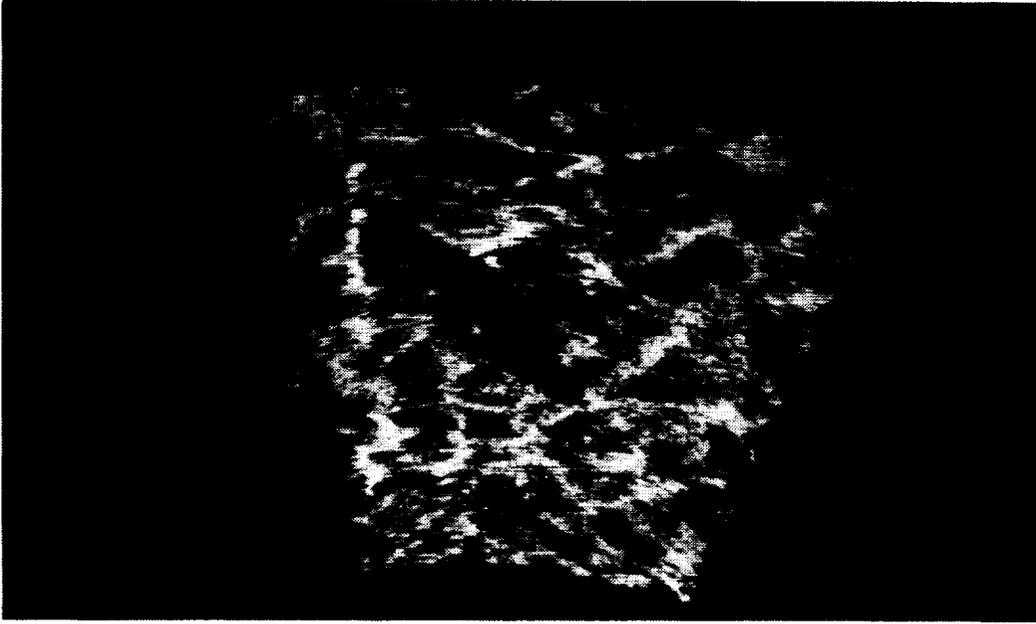
Figure 3 Azimuth/Range Radar Image of Runway and Environs
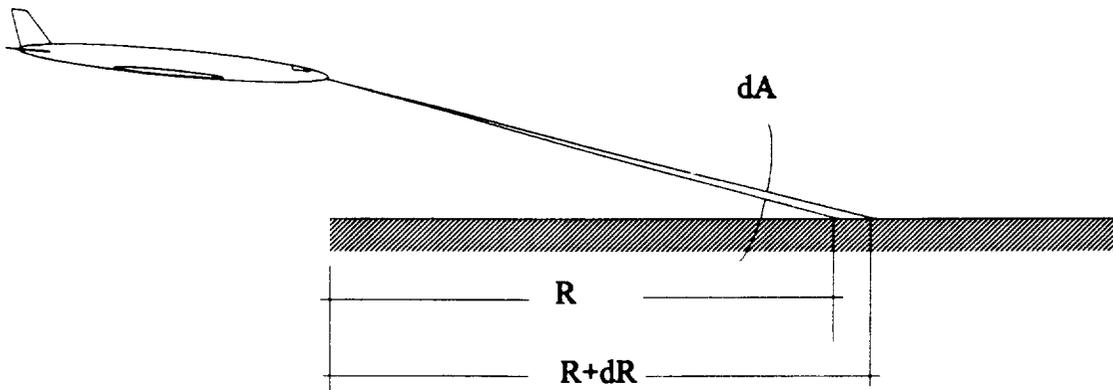
Figure 4 Conversion from Radar Range to Elevation
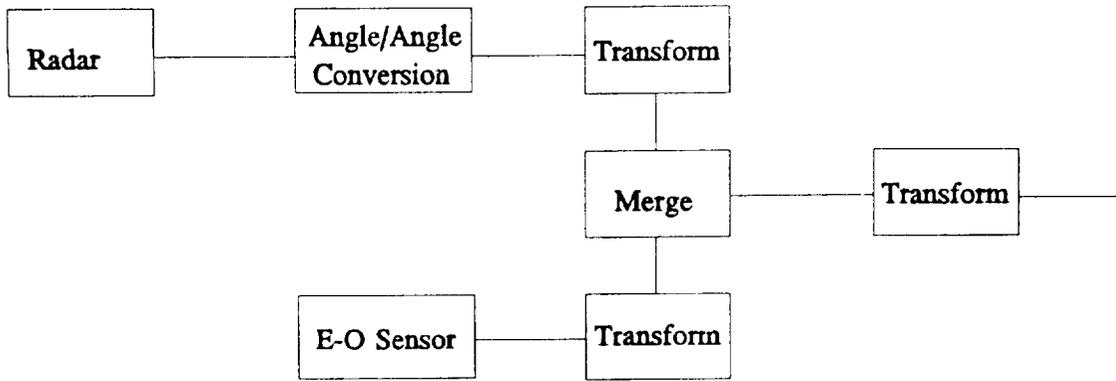
Figure 5 Radar/E-O Fusion Using Pyramid Transform
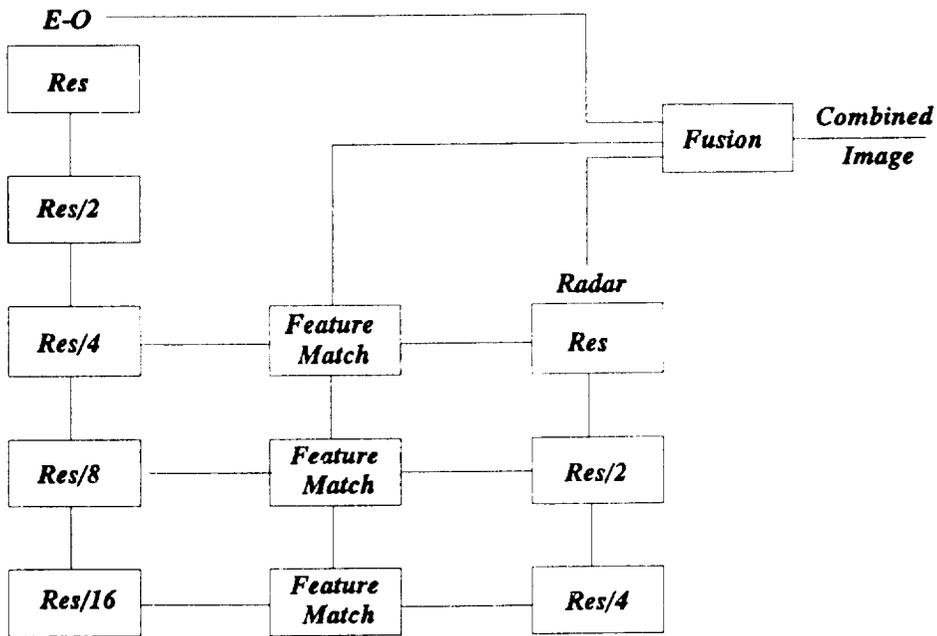
Figure 6 Reduced E-O Resolution Matches Radar Resolution
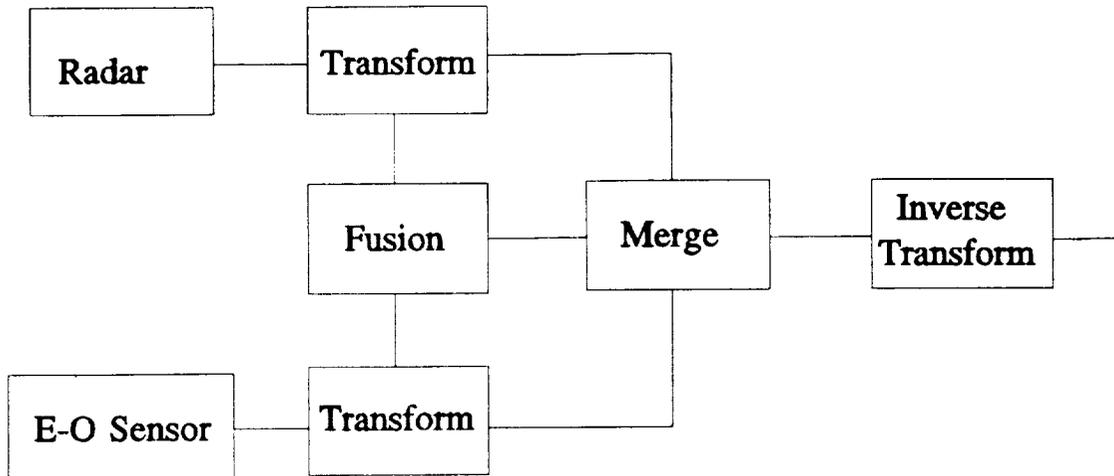
Figure 7 Generalized Radar E-O Fusion Using Transforms

IV. IMAGE PROCESSING: COMPUTER VISION