

SAR and HSI Data Fusion for Counter CC&D¹

Su May Hsu², John P. Kerekes, Hsiao-hua Burke and Steve Crooks
MIT Lincoln Laboratory
244 Wood St. Lexington, Mass. 02420-9108

Abstract

There have been several examples in which both Synthetic Aperture Radar (SAR) and Hyperspectral Imaging (HSI) systems collected data in support of military operations (SMO). FOPEN (Foliage Penetration) radar has been used to penetrate tree canopies in order to detect objects. On the other hand, spectral differences between targets and backgrounds are used in HSI systems. Both SAR and HSI systems may suffer substantial false alarm and leakage rates due to respective background clutter. It is expected that a combined SAR and HSI system will greatly enhance the detection and identification performance.

Based on the features derived from SAR and HSI data, a fusion approach has been established. Data sets of SAR and HSI over a common area from the Dixie data collection (May 1997 from Vicksburg, Mississippi) are used in this paper to demonstrate the fusion approach. The site contained several camouflage nets and vehicles. One of the vehicles was covered under a camouflage net. Target detection will be shown for each data set based on RCS (Radar Cross Section) and spectral features. In particular, a transformation of the spectral measurements into principal components was used to reduce the dimensionality of HSI data as well as to facilitate spectral feature extraction and material identification. SAR and HSI detections were subsequently combined via image co-registration. The fusion results showed that false detections in the SAR image were greatly reduced with background characterization of trees from HSI and target detections were confirmed with detection of camouflage nets and material identification of vehicle paints.

Introduction

Principles of low frequency SAR and Hyperspectral imaging are different and their detection capabilities often complement each other. FOPEN SAR operates at 20-700 MHz. It penetrates foliage and detects targets under tree canopy, but has significant clutter returns from trees. Hyperspectral imaging, on the other hand, is typically in visible to SWIR wavelength region, has fine spectral resolutions ($\Delta\lambda = 10$ nm), is capable of subpixel detection and material identification. But it provides no surface penetrations and is often limited to nadir viewing geometry.

It is possible that a combined SAR/HSI system could have the imaging sensors cue each other in joint observations. Potential fusion applications include counter camouflage, concealment and deception (CC&D) and surveillance of exposed sites. As a scenario for CC&D application, HSI allows detection of camouflage material and FOPEN SAR differentiates metal vehicles from non-radar reflecting decoys. As an example for surveillance application, FOPEN SAR locates suspected targets and HSI derives terrain characteristics to reduce SAR false alarms.

A common data set from Dixie-97 data collect over Vicksburg, Mississippi is used here to demonstrate the framework of SAR/HSI fusion. Both P-3 UWB radar (215-730 MHz) and HYDICE (Hyperspectral Digital Image Collection Experiment, 0.4-2.5 μm in 210 bands) collected data at the site. Figure 1 shows the composite data set. A sketch of the target site is also included in the figure. Targets in the forest background included camouflage nets and vehicles. Several camouflage nets were populated along the tree line around an open area, one camouflage net was in the open. One camouflage net at the tree line was covering a vehicle. All other nets were either empty or covering non-radar reflecting decoys. In addition, there was one vehicle obscured at the lower right corner of the sketch and another vehicle was partially exposed near the top left corner. The SAR data was collected with a 32° depression angle and a ground sample distance (GSD) of 0.23m x 0.4m. The HSI data was collected at 1.5 km altitude with a nadir viewing geometry and GSD of 0.76m x 1.1m.

For the Dixie data collect, a SAR/HSI fusion strategy is established based on their detection characteristics. SAR and HSI data are first processed separately for detection and terrain classification, respectively. Then co-registration is performed to allow overlay of the images. SAR false alarms from trees are reduced by terrain mapping, detection of concealed targets under camouflage nets is verified and detection of partially exposed targets is further confirmed with material identification by HSI. In this paper, analysis of the HSI data is first given in the next section. Then SAR/HSI image co-registration and the fusion results are illustrated in the last section before summary.

HSI Data Analysis

Class spectra of backgrounds of road, tree, grass and camouflage nets are plotted as a function of wavelength in Figure 2. The road spectrum is significantly higher than other spectra in the short wavelength region. Grass and tree spectra exhibit a decrease at .68 μm followed by a large increase into near infrared, since green plants use chlorophyll to absorb the visible light from the sun, and reflect the infrared radiation. There are other less significant spectral differences among the classes over the wavelength region of 0.4 μm to 2.5 μm in 210 bands. In order to extract the spectral features leading to further analysis, reduction in spectral dimensionality is applied to the HSI data cube. Principal component transform is generally used to de-correlate data and maximize the information content in a reduced number of features (Schott, 1997). The covariance matrix is first computed over the pixel spectra contained in the HSI data cube of interest. Eigenvalues and Eigenvectors are then obtained for the covariance matrix. Using the Eigenvectors as a new set of coordinate system, the HSI data cube is then transformed into principal components, also called Eigenimages. The Eigenimages associated with large Eigenvalues contain most

of the information while the Eigenimages associated with small Eigenvalues are noise-dominated. Thus principal component transform allows segregation of noise components and the determination of the inherent dimensionality of the HSI data.

Some of the principal components calculated from the HSI data over Dixie are shown in Figure 3. Background classes of open area, trees and roads are apparent in the first and third components. Camouflage nets appear with strong contrast to the backgrounds in the seventh component. Class spectra in Eigen space are plotted in the lower right corner of Figure 3. It shows that the scene-dominating background classes have significant features in the first several components. The camouflage nets, on the other hand, show up at the sixth and seventh components where the background spectra have values close to zero. A matched filter was constructed from the mean of several pixels extracted from the nets. Matched filtering and thresholding are then applied to the HSI data to detect all pixels of camouflage nets. Figure 4 shows the camouflage net detection. Result of background mapping of the scene is also included in the figure. Roads, grass, trees and shadow are shown as separate terrain classes. These are results of an iso-data clustering operation using the first five principal components. Iso-data clustering is an unsupervised classification method. It first calculates class means evenly distributed over the data space and then iteratively clusters the image pixels using minimum distance techniques. In each iteration, it recalculates means and reclassifies pixels with respect to the new means. The process continues until the number of pixels in each class changes by less than a selected threshold or the maximum number of iterations is reached. The target detection and background classification in the image also allow calculation of class statistics. Such statistics can be used in model-based analysis for forecasting HSI system performance (Kerekes, 1996).

Combined SAR/HSI Analysis and Fusion

To combine SAR and HSI detection results, co-registration is first performed with reference to terrain features such as open and tree areas using scaling, rotation and translation operations. Fusion is then carried out based on the co-registered images. This is illustrated in Figure 5. SAR data is first processed with pixel grouping and thresholding. Target detection with threshold set at 6 dBsm is shown in magenta on the left. Incidentally, a power line in the scene is detected as a near vertical line shown in yellow at the top right portion of the SAR image. The terrain map derived from HSI data with camouflage net detection is depicted in the middle panel of Figure 5. Combining the analyses, only those SAR detections located in either open area or around camouflage nets indicated in HSI are retained. SAR detections that coincide with HSI identifications as trees and are far from open areas or camouflage nets are considered false alarms. The combined detection result is shown on the right of the figure. A SAR detection of vehicle appears under a camouflage net at the top-right corner. Other nets are empty with no SAR detections. There are several strong SAR detections at the left side of the open area. A spectral angle mapping algorithm is conducted to match HSI data in the area to our spectral library of paints. Three pixels match well with military gray-tan paint. This indicates the presence of a possible military vehicle and thus confirms the SAR detection.

Summary

A common data set of P-3 SAR and HYDICE HSI from Dixie-97 data collection over Vicksburg, Mississippi has been used to demonstrate the framework of SAR/HSI fusion. Targets in the forest background included camouflage nets and vehicles. Principal component analysis on HSI data was shown to allow effective spectral dimension reduction and feature extraction for terrain characterization and camouflage net detection. SAR/HSI fusion was accomplished with a co-registration of the images using references to terrain characteristics. The fusion results showed detection of a vehicle under a camouflage net and a significant reduction of SAR false alarms due to trees. In addition, a case of SAR detection was confirmed by HSI with material identification of military vehicle paint.

References

Schott, J. R., Remote Sensing, Oxford University Press, 1997

Kerekes, J. P., Spectroradiometric System Analysis: A Feasibility Demonstration, MIT Lincoln Laboratory, 1996

¹ This work was sponsored by the Department of Air Force under Contract F19628-95-C-0002. Opinions, interpretations, conclusions and recommendations are those of the authors and not necessarily endorsed by the United States Air Force.

² Telephone (781) 981-2920; Fax (781) 981-7271; e-mail sumayhsu@ll.mit.edu

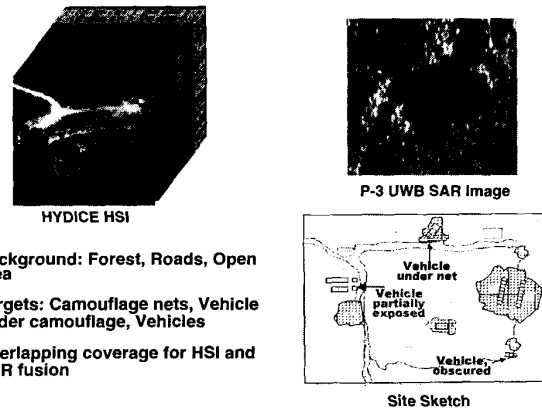


Figure 1 Common data set of SAR/HSI from Dixie data collect, May 1997

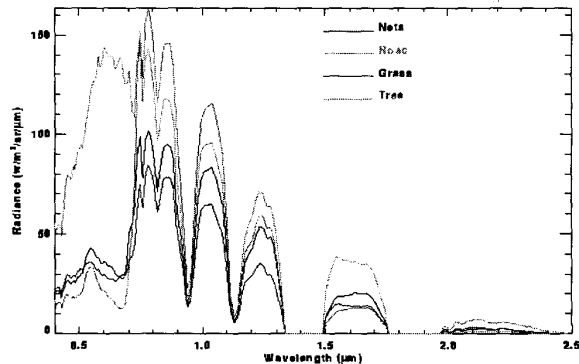


Figure 2 Class spectra of backgrounds and camouflage nets from HYDICE

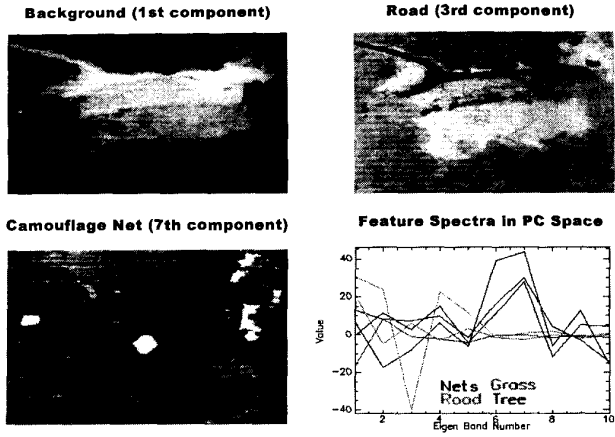


Figure 3 Principal components calculated from the HSI data over Dixie data collect

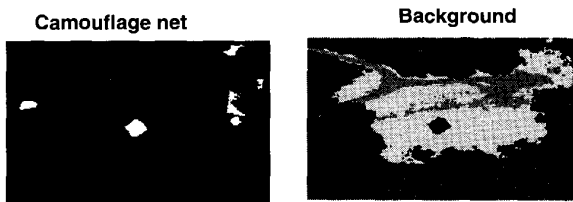


Figure 4 Results of camouflage net detections and background classification

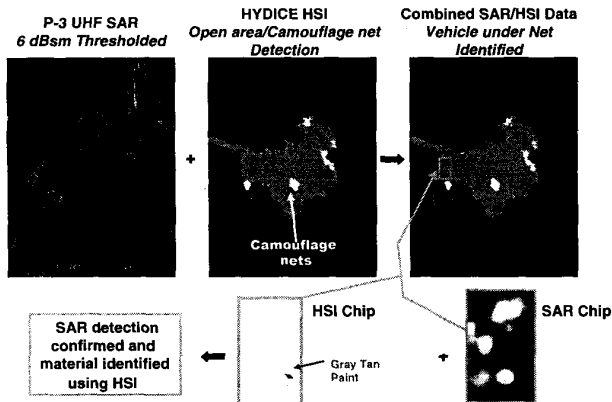


Figure 5 Highlights of SAR/HSI fusion of detections