FUSION OF DIGITAL MULTISPECTRAL VIDEOGRAPHY WITH INTERFEROMETRIC SYNTHETIC APERTURE RADAR

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ABSTRACT

As new remote sensing systems possessing different spectral and spatial capabilities become available, the fusion of sensors utilizing different regions of the electromagnetic spectrum will accelerate. This paper describes the techniques used to merge interferometric synthetic aperture radar (IFSAR) with digital multispectral videography (DMSV). A thirty-five frame digital multispectral mosaic was constructed and merged with the Digital Elevation Model (DEM) and backscatter layers derived from an IFSAR airborne X-band radar system. Two methods were incorporated in an effort to utilize the combined DMSV-IFSAR data. First, a comparison was made between minimum distance classifications run using the DMSV data only, and with the DMSV combined with the IFSAR backscatter file. Results show that classification accuracies improved when separating trees from other green vegetation. Second, a simple cosine correction algorithm derived form the IFSAR DEM was used to radiometrically adjust the DMSV data for slope and aspect effects. The utility of this technique was not conclusive. However, a small test area consisting of a grass cover type appears to have been successfully modified.

INTRODUCTION

Traditionally, land-use managers have looked to a single remote sensing method or instrument to supply data over large areas where ground sampling would be expensive or impossible to obtain. Visible-near infrared (VNIR) systems have often been used to derive land cover, land use, change detection and vegetative vigor among many applications. Thermal systems have been utilized for sea surface temperatures and geologic applications, while passive microwave sensors have been used for soil moisture determination. Additionally, radar systems have been used for a wide variety of applications especially over geographic regions where cloud cover reduces the usefulness of optical sensors. Other factors that influence the decision of which sensor technology to utilize includes spatial and temporal resolution, data availability, and collection/processing cost.

With the passing of time, a wider array of instruments, both airborne and spaceborne, have become available that offer improvements over previous sensors. These improved sensors give land-use managers another dimension of data that can be used to supplement and validate their primary data collection systems. Data fusion (or sensor fusion) combines data from sensors in an effort to obtain more information than can be collected from any instrument alone. For example, combining VNIR data with thermal data will yield information about a feature's reflectiveness and emissivity. A technology that has recently become available is interferometric synthetic aperture radar (IFSAR). By using IFSAR technology, two types of data can be obtained with a single pass of the instrument. The first type of data is the traditional backscatter image which is similar to other synthetic aperture radar systems. The second data type is a digital terrain model, which can be collected with a single pass because the two return antennas on IFSAR systems give a stereo view of the area being imaged..

The objective of this study was to supplement digital multispectral videography collected over Glasgow, Missouri, with both the IFSAR backscatter data and DEM model. Previous research has shown that combining multispectral data with radar has improved classifications over spectrally similar features (Haack, 1994, Brisco and Brown, 1995, Harris et. al. 1990). Also, the use of DEMs, for correction of illumination effects (Jones et. al. 1988, Leprieur, et. al., 1988), and as an input layer into a classification or post classification scenario have been studied (Shasby and Carneggie, 1986). In this study, the backscatter data from the IFSAR system was combined with the DMSV data and was analyzed using a minimum distance classification algorithm. Additionally, a simple cosine correction model was used with the IFSAR DEM in an attempt to reduce radiometric effects due to terrain slope and aspect.

SITE SELECTION AND DESCRIPTION

The site selected for this study was the town and surrounding area of Glasgow, Missouri. Glasgow is located about halfway between Kansas City and St. Louis on the South bank of the Missouri river. This site was selected due to it's wide variety of land-cover types (i.e. rivers, ponds, creeks, urban, suburban, forest, agriculture) and because of the damage caused by flooding during the summer of 1993.

The digital multispectral imagery was collected on 22 June 1996 from 1130 - 1300 central daylight savings time. The sky conditions were clear but with a slight haze. The Missouri river at that time was high, fast flowing and silty but was within it banks. Flooding from the spring rains was still evident in some agricultural fields close to the river. Vegetation was healthy and turgid due to plentiful moisture and the deciduous trees were fully foliated. Corn and wheat crops surveyed before the flight had grown to a height of about 1 meter, while soybean plants were about 20 cm tall.

The IFSAR data was collected on 11 November 1994 as a test site for ERIMs Interferometric Synthetic Aperture Radar for Elevations (IFSARE). The only significant change noted between the IFSARE and DMSV data (Nov 1994 - June 1996) was the modification of a river bank levy. No data from this area was used in ~~the~~ any of the analysis presented here.

DATA DESCRIPTION

DMSV The digital imagery to be mosaicked for this project was obtained with the U.S. Army Topographic Engineering Center (TEC) Digital Multispectral Video system (DMSV). The DMSV system is comprised of four charged coupled device (CCD) cameras with 24-mm focal length lenses, a ruggedized 486 PC, 32 Megabytes of RAM, a 500 Megabyte hard disk, and a 4 Megabyte AT Vista RasterOps framegrabber board. Each of the four cameras were fitted with a 25-nm bandpass interference filter. These filters were centered at 450-nm, 550-nm, 650-nm, and 750-nm. The four bands are captured simultaneously and stored on internal RAM. Each 8-bit, 740 x 578 pixel four band frame is a little over 1.7 Megabytes, which allows for the collection of 17 frames before the data must be transferred to the PC hard drive.

The Virginia Institute of Marine Science (VIMS) DeHaviland "Beaver" served as the aerial platform for this project. The imagery was collected at an altitude of approximately 10,000 feet above mean sea level which resulted in a spatial resolution ~ 1 m/pixel. Twelve flight lines of 11 images each were flown from south to north. The endlap averaged about 40 percent while the sidelap varied from 0 to 80 percent.

DGPS Differential Global Positioning System (DGPS) data was collected at 16 points throughout Glasgow and vicinity. Of these 16 points, 7 fell within the area covered by the DMSV imagery. These DGPS positions were used to register the completed photomosaic to geographic coordinates. The DGPS data was collected using a Trimble 12-channel community base station and a Trimble 12-channel Pro-Excel data collector. The Trimble software package Pfinder v2.54 was used to post-process the differential data. The base station was positioned over a NGS second-order horizontal control point located approximately 7 km from Glasgow. Each of the DGPS points collected in Glasgow were integrated for 3 minutes (180 points).

IFSARE The IFSARE backscatter file of the Glasgow area is shown in figure

Figure 1. IFSARE backscatter image of Glasgow, MO.

1. The IFSARE is an X-band system ($\lambda \sim 3$ cm) which uses two receiving antennas. The advantage of having two receiving antennas on the same platform allows the IFSARE to create digital elevation models with only one pass of the sensor over the area of interest as opposed to two with a traditional synthetic aperture radar systems. The IFSARE system currently resides on a Learjet 36 aircraft and is integrated with DGPS and a ring laser gyro-inertial navigation unit which provides accurate aircraft position and orientation. The resulting products from an IFSARE data collection are a synthetic aperture radar image (the backscatter file), a correlation image between the two antennas (the correlation file), and the digital elevation model. All of the data is geocoded and orthorectified. There is no down-linking or processing capability aboard the aircraft. All data must be stored on magnetic media and processed in the laboratory. Processing is done on a Cray YMP supercomputer, the computation time required is approximately 50 hours for each hour of data collected. Typical IFSARE operational parameters are shown in table 1 (Kramer 1995)

Table 1.
IFSARE operational parameters.

Frequency	9.5 GHz (X-band)
Polarization	HH
RF Bandwidth	67.5 MHz
Ground swath width	10 km
Near range	15.3 km
Far range	22.8 km
Flight altitude	12.2 km
Data collection coverage	100 km^2/min
Slant Range resolution	2.5 m
Nominal ground resolution	3 m
Height accuracy	3 m
Horizontal position accuracy	2 m

The IFSARE, like other radar systems, constrained by several factors. Highly specular surfaces such as water or very flat, new asphalt will produce no return signal and thus no elevation for that area. Also, where terrain slope is high (> 35 degrees), radar shadow cast by the terrain will become significant. Bright targets, such as buildings and cliff faces, and moving targets such as cars and trucks, can produce variable radiometric anomalies in the data.

** Disclaimer Statement: The identification of brands and models of equipment, materials or computer software, does not constitute or imply an endorsement of these products by the U.S. Government or it's agencies.

METHODS

DMSV Mosaic The thirty-five frame digital mosaic derived from the DMSV data was created using techniques similar to film mosaics. Image **i** of flight line **2** (or image **2i**) was selected as the base image and all other images were mosaicked working outward. A first order six parameter affine transformation was used to merge each frame to the mosaic. Ground Control Points (GCPs) were selected by an analyst and the root mean square error (RMSE) of the transformations were kept below 0.5 pixels. Within flight-line radiometric discontinuities due to vignetting, optical and geometrical effects (Fischer, 1997) were addressed using a method similar to Pickup (1995, 1996) and Neale et. al. (1996) . An empirical calibration matrix to counteract the radiometric discontinuities was created using the DMSV data itself. The assumption of this technique is that such a large number of images were collected over Glasgow (> 130), that the average of theses images (per band) should be radiometrically flat. Any deviation from this "flat" image would be due to one or a combination of the above effects. An inverse mask was then derived form these average images and applied to every frame. The validity of this method was qualitatively checked by performing the same technique using pixels obtained only from the spectrally homogeneous Missouri River.

Radiometric discontinuities between flight lines due to temporal effects were normalized using statistical normalization (Fischer 1997, Morrisette et. al. 1996). Image **2i** was selected as the base image and all other frames were normalized to it using the formula:

$$DN_N = ((DN_O - \mu_O)/\sigma_O)\sigma_M + \mu_M$$

where μ and σ are the mean and standard deviation respectively. The combination of these techniques to remove radiometric discontinuities within flight lines and between flight lines produced an almost seamless mosaic (figure 2).

Figure 3. DMSV mosaic of Glasgow, MO.

DMSV-IFSARE Merge The IFSARE data was originally collected at 5 meter resolution and therefore was resampled to 1 meter pixels (factor of 5) to match the spatial resolution of the DMSV data. Common GCPs were selected from both the DMSV and IFSARE magnitudes file and a 2nd order polynomial transformation was used to warp the DMSV mosaic to the previously georectified IFSARE data. The resulting RMSE value was approximately 7 pixels which corresponds to about 1.4 pixels when noting that the IFSARE data had been resampled by a factor of 5.

RESULTS AND DISCUSSION

The first technique used to exploit the combined DMSV-IFSARE data set was comparing minimum distance classifications utilizing the four DMSV bands alone, and the combined DMSV-IFSARE backscatter data. The classification parameters were set in order to insure that all pixels were classified. Two sets of signatures from each cover type were used to train the classification and two sets were used to check the results after classification. The error matrix using only the DMSV bands is shown in table 2, while the combined DMSV-IFSARE backscatter error matrix is shown in table 3. Analysis of these tables reveals several interesting results. First, by including the IFSARE backscatter file in the classification, accuracy in delineating forest cover from other green vegetation was improved (82% to 90%). This result was expected because the backscatter signal from large, woody features should be stronger than from grasses and low growing agricultural crops. A second result from the classification shows that accuracy decreases considerably when classifying grass from other low growing vegetation types. This also was not an unexpected result because the backscatter signature from grass would not be markedly different from wheat or other short vegetation. Another, and possibly equally significant effect, could have been caused by the seasonal difference of the agricultural fields between the DMSV and IFSARE data collections. These results show that inclusion of the IFSARE backscatter file may improve classification accuracy between broad cover groups (i.e. forest, urban, grasses, water, etc...), but may be of minimal use when trying to separate similar cover types (such as wheat and tall grass).

A second technique used to exploit the combined data was to use a simple algorithm to compensate for slope and aspect illumination effects in the DMSV imagery utilizing the IFSARE DEM file. The technique used was the cosine correction (Teillet, 1982) shown below and diagramed in figure 3.

$$DN_N = DN_O(\cos\theta/\cos i)$$

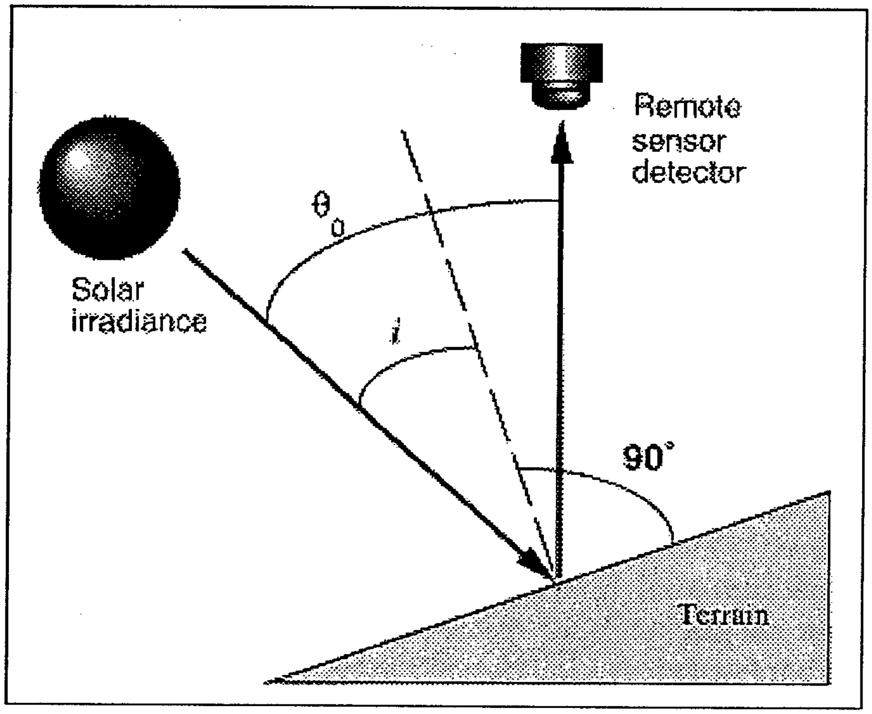

Figure 3. Representation of cosine correction (From Jensen, 1996).

In general, this technique over-corrected shaded pixels, especially the shadow side of tree canopies and other relatively tall features. To offset this effect, a constant (known as the Minnaert constant) can be introduced so that the cosine correction becomes (Teillet, 1982):

$$DN_N = DN_O(\cos\theta/\cos i)^k$$

Where **k** is derived empirically. The utility of this additional parameter will be considered for future investigation.

This simple correction technique appears to have been effective in compensating for slope and aspect effects in at least one case. Figure 4a shows the elevation change in the northern direction for a grass meadow. The solid line of figure 4b shows the pixel value (and least squares line) of the 750 nm band over the same area. The dashed line shows the pixel value (and least squares line) after application of the cosine correction model for the same band. This result shows that the slope of the least squares line for the corrected pixels has been successfully adjusted toward zero. However, the range of values away from the least squares line has increased for the corrected case. Again, inclusion of the Minnaert constant **k** may improve this result but has yet to be tested.

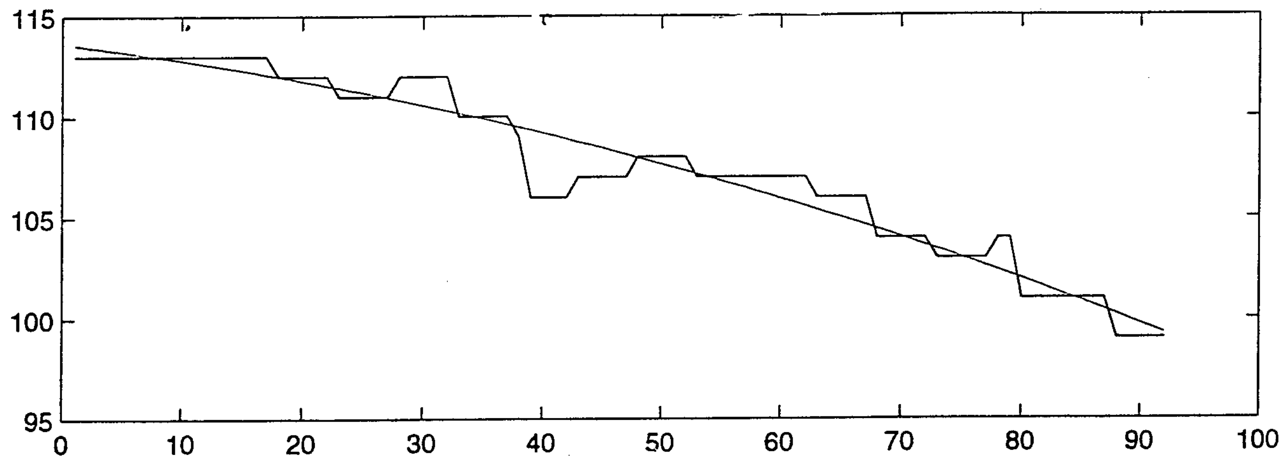

Figure 4A

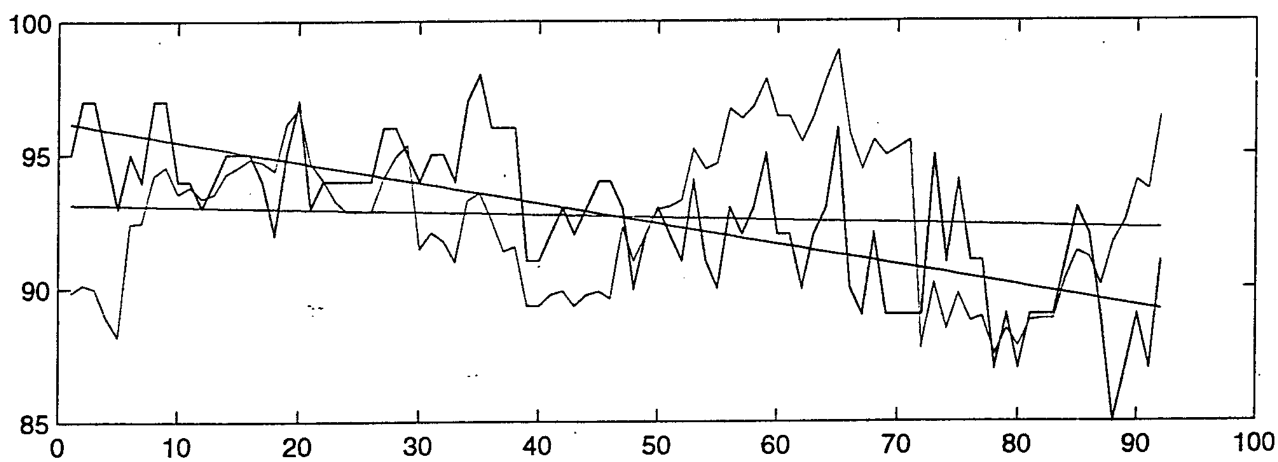

Figure 4B

CONCLUSIONS

As a wider variety of sensors become available, land-use manages and other resource officials will have access to a broader array of techniques on which to extract information. Data from IFSAR technology may prove to be a useful supplement to more traditional photography and videography. This brief study shows that both the backscatter data and digital terrain model obtained from IFSAR systems may be utilized. However, further study needs to be conducted on issues such as spatial resolution, algorithms implemented, and classification techniques to be employed.

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