Decision Fusion of Hyperspectral and SAR data for Trafficability Assessment

Capt. Pierre Chouinard
Canadian Forces
Rochester Institute of Technology
Rochester, NY
email: pfc0232@cis.rit.edu

John Kerekes
Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology
Rochester, NY

Abstract— **This paper highlights the complementary nature of SAR and HSI data in the context of a trafficability assessment. To perform the assessment, different types of classification on the two data sets were performed and fused at the decision level. Results show different strengths for each data set and prove the advantage of using both HSI and SAR data in trafficability assessment.**

Keywords-component; Decision Fusion, Trafficability, Hyperspectral and Synthetic Aperture Radar.

I. INTRODUCTION

Synthetic Aperture Radar (SAR) and Hyperspectral Imaging (HSI) data can be analyzed to derive a wide variety of information relevant to many spheres of activities. SAR is a form of specially processed radar that can use different bands of the radar section of the electromagnetic spectrum to give information about the backscattered energy. This energy is influenced by the dielectric constant and the geometry of imaged materials. HSI is a passive way to remotely sense areas and uses several narrow spectral bands located in the visible and the NIR. We can therefore appreciate that, by their very different nature, SAR and HSI seem to complement well each other.

In this work, we explore the SAR and HSI complementary nature in the context of a trafficability assessment. Trafficability is the measure of how easily vehicles can drive through a particular piece of terrain [1]. For this research, the information will be expressed qualitatively and will be the product of a decision fusion of HSI and SAR data.

In the following paragraphs, we first further define trafficability and its context, we revisit the concept of complementarity between SAR and HSI, we explain the data combination process used, we present the data sets and the obtained results and we finish by presenting conclusions and suggesting areas of improvement.

II. TRAFFICABILITY

In order to assess the trafficability over a certain area, different aspects of the terrain have to be evaluated. In this work, we are using vegetation, terrain slope, hydrology, transportation networks, soil and obstacles. However, other data can be considered such as weather, recent traffic movement and protected areas [1], but were not considered for this research due to the lack of ground truth.

The characteristics of the vehicle play an important role in trafficability. For example, how wide a vehicle is will tell if it can pass through a forest or not. Considered characteristics are usually maximum vehicle speed, minimum turning radius, override capability and vehicle width and length [2]. In this research we are assessing trafficability for a M151 jeep.

III. SAR AND HYPERSPECTRAL COMPLEMENTARITY

A. *SAR Usage*

SAR data can be used to quantify vegetation characteristics useful for trafficability assessment [3]. Biomass is a good indicator of the vegetation density and can usually be recovered within a certain range of precision and values from SAR data. Stand height and density can help determine if a vehicle can stampede the vegetation or will be blocked by it. Moisture content of the soil under the trees' canopy can be recovered from low frequency SAR data, however it plays a minor role in trafficability as most of terrain having trees is usually already classified as not trafficable.

Using imaging radar interferometry, it is possible to generate Digital Elevation Maps (DEMs) of a remotely sensed area. Interferometric SAR combines images recorded by antennas at different times or locations to achieve resolution approaching the order of the wavelength used. Then, the DEM combined with a slope detection algorithm can identify areas where slopes are too steep for a vehicle to safely travel.

SAR can detect water features and the detection accuracy depends largely on the neighboring areas. The smooth surface of water directs most of the radar backscattering away from the sensor as opposed to normally rougher surrounding land surfaces. SAR data can provide bathymetry information up to a certain extent [4]. The water aspect of trafficability largely depends on the vehicle type as some can cross rivers and other are immobilized by small streams.

SAR can locate transportation networks to a certain extent. Similarly to water, roads are smooth and therefore direct the backscattered radiation away from the sensor. Therefore, roads are in a better position of being identified if they are surrounded by diffuse scatterers. The particular orthogonality of transportation networks in cities can be taken to advantage by using multi-polarization SAR data to improve classification [3]. Areas identified as a part of a transportation network are labeled as trafficable.

Soil texture, roughness and moisture content can be recovered from SAR data, and therefore soil types having different values for those characteristics can be discriminated. However, SAR is often used in geology to evaluate moisture content. Soil type and moisture are necessary in trafficability to identify if a vehicle will be able to move or will get stuck over a certain area.

Obstacles consist of man-made objects and natural objects that vehicles can not move over, such as buildings, walls and big boulders. Man-made features usually have intense backscatter as most of them are placed orthogonally to the radar signal which creates a dihedral effect. When an obstacle is detected, the studied area is classified as not trafficable.

B. *HSI Usage*

HSI can be used to spectrally identify types of vegetation [5]. This information can contribute modestly or greatly to the trafficability depending on the type of classification done; a category classification such as: grass and herbs, bushes and shrubs and mature trees can be off base when associated with trafficable and non-trafficable terrain as opposed to a species type classification which requires forestry knowledge and additional information to be able to confidently assess trafficability. HSI can also be used to assess biomass, stand density and forest structure.

HSI imagery is not recognized to have topographic mapping capabilities and therefore cannot help with this aspect of trafficability.

HSI has proven its capability to identify hydrology networks; absorption bands at 940nm and 1.14μm can be recognized and utilized to label pixels as water [6]. Further analysis can be done to recover other information such as bathymetry, bottom type and coral reefs. Knowing the presence and the depth of water is required in trafficability assessment.

The spectral signature of asphalt and other road constituents can be identified by HSI instruments. This allows a scientist to identify transport networks which are considered as trafficable areas.

Extensive work has been performed with HSI data to categorize soil. This has resulted in the creation of spectral signature libraries of common soil constituents that can be used for classification. The type of soil of an area can be used to determine its strength and granularity which will impact trafficability. However, to have a very good assessment of the situation, the soil type information has to be augmented by the soil moisture content.

Obstacles include escarpments, embankments, road cuts and fills, depressions, fences, walls, hedgerows, and moats. As some of them are tracked with using a DEM, obstacles such as buildings can also be detected by HSI.

C. *Complimentarity*

HSI and SAR have different characteristics that can often complete each other. First, HSI instruments are looking at wavelengths generally ranging from visible to near/mid-infrared and SAR is sensing one or multiple radar bands. A particularity of those imaging radar bands is that it can see up to a certain extent through clouds and other precipitations which is impossible to do in the VIS-NIR region of the spectrum and therefore SAR can complete the HSI coverage.

Also, another important complimentary effect is the fact that HSI instruments are passive and SAR instruments active. HSI instruments can be therefore only used when an external source is producing radiations as opposed to SAR that can be used at any time.

Most of the HSI instruments are looking directly under themselves or as close as possible to that position. By definition, SAR instruments are side-looking which produces a total different geometry of illumination. Even though both types of data go through orthocorrection, the relatively big difference in instrument/look-angle/target geometry makes certain surfaces not sensed in one type of data sensed in the other.

IV. DECISION FUSION

A. *Pre-Processing*

Data pre-processing refers to the important process of calibrating the image to represent as precisely as possible the radiation or the reflectance of the area of interest. Noise and speckle reduction are an important part of data pre-processing for HSI and SAR images, respectively. Applying different types of filters to the data is usually the way to reduce the noise and speckle but often comes to the price of a reduced resolution.

Variations of the relative position between the sensor, the view angle and the target causes certain distortions in data representation as most remote sensing images should display features as if they were directly seen from above. With the help of DEM and precise information about the location, speed, view angle of the instrument and time at all recording times, the geometry can be recreated and transposed from the instrument to a straight from above perspective free of Earth rotation, land curvature, sensor speed variations and other distortions sources.

Before fusing two or more data sources together, special attention has to be placed on correctly associating respective elements of one source with the corresponding elements in the other sources. Different techniques are currently available to register files, some automatic, others requiring inputs from the user, some associating features, others pixels, some applying simple translation to elements of a data set, others applying polynomial equations.

B. *Fusion*

Combining the information of different sources can be done at three different levels: pixel, feature and decision. A pixel level fusion combines pixel information on a pixel-to-pixel basis. For feature level fusion, segmented parts of original images are merged together. Finally, decision fusion combines the results of interpretation of each single data set into one final decision. Feature level fusion has the advantage of being simpler than decision fusion but more complicated than pixel level fusion; however, feature fusion requires higher level of accuracy during the registration than decision fusion but less than pixel fusion.

C. *Decision Fusion Approach*

In this research, two main methods will be used for fusion: one based on logical operators and another based on weights generated by accuracy of classification of the separate data sets.

The decision level fusion can be refined to a certain extent. The coarser level consists of a strict final Go/No Go combination coming from the assessment made separately on the SAR and HSI sets, this way the data sets are not fused together until the very end of the process. A more flexible method is to fuse the trafficability results of each trafficability criterion to each other; that way fusion between the data sets is performed for each criterion. Finally, instead of fusing trafficability for each criterion, separate classification coming from the SAR and HSI sets can be combined to generate the trafficability assessment for each trafficability criterion.

V. EXPERIMENTAL DATA AND RESULTS

A. *Location*

The study area is located in the vicinity of the Yellowstone National Park North-East area. It is spreads over Idaho, Montana and Wyoming and includes the towns of Cooke City and Silver Gate. The area can be described as rural and is composed of a variety of terrain types and slopes with an dominant coniferous presence.

B. *HyMap*

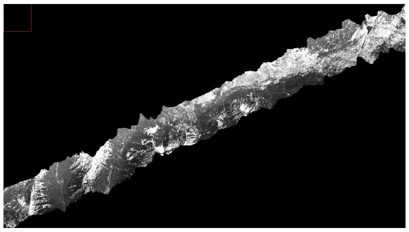

Fig.1 HyMap 450nm band

The HSI data set studied was produced by HyMap. HyMap is a HSI instrument that records 126 bands from 0.45 to 2.5µm having width between 15 and 20 nm. It is commercially available and built by Integrated Spectronics. The resolution of the studied image is 4.9 m [7].

C. *AirSAR*

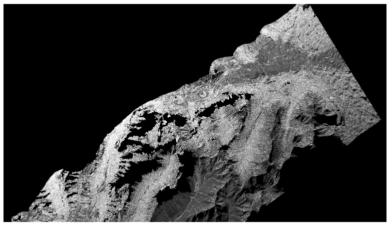

Fig.2 AirSAR C-VV

AirSAR was used to produce the SAR data set studied in this research. It is managed by the NASA Jet Propulsion Laboratory and flown on a DC-8. It covers all four polarizations in the C, L and P bands, however for this particular set, only one polarization is available in the C-band at the profit of a DEM, an incidence map and a correlation map. The resolution of the studied image is 5 m [8].

D. *Classification*

Classification was an important step of this research as each classification has the potential of ruling out if an area is trafficable or not. Because fusion was applied at the decision level, separate classifications were performed on the two different data sets. Simple supervised classifications algorithms were applied to the data for all classifications, such as parallelepiped, minimum distance, Mahalanobis distance, Spectral Angle Mapper (SAM) and Maximum Likelihood and the one offering the best result was selected [9].

The DEM was provided with the AirSAR TOPSAR data set and, combined with an IDL routine, it was possible to identify abrupt areas that could drastically slow down or completely put a vehicle to a stop accordingly to reference [2].

Vehicle capabilities were based on web-available documents produced by the US military for trafficability assessment [2].

E. *Fusion*

The data provided was already pre-processed by the providers, however, due to the speckle content of the AirSAR image, a Frost filter was applied on the data.

As opposed to the AirSAR data, the HyMap HSI data was not already orthocorrected. The correction was performed using a provided look-up table and ENVI.

Registration was done by first rotating the AirSAR data set to a similar angle to the georegistered HyMap data. After selecting several Ground Control Points (GCPs) between the two data sets, a second degree polynomial equation transformation was performed on the data with the help of ENVI. GCPs were selected and discarded until error was within an acceptable range.

As described previously, two types of fusion will be applied on resulting classifications from both data sets; one using logical operators and the other using weights based on the accuracy of the data. Also the three levels of decision fusion laid out in the previous sections will be investigated.

F. *Evaluation*

Evaluations will be conducted at two different times during the process; first, after each initial classification realized on the different data sets and the second after the resulting SAR and HSI decision was fused together.

Ground truth information about the area was available from different sources. Rasterfiles and topographic maps representing the roads and hydrology networks were used to trace ground truth regions for those two criteria. It was assumed that the presence of any water sources would compromise any vehicle movement because ground truth bathymetry data was not available for water features within the studied data sets. High definitions photos were used to identify buildings. Vegetation and soil maps were used to estimate the trafficability of the studied areas. Weather reports produced during the period of time the data collection were consulted, and it was concluded that soils could be assumed as being dry. Classifications methods were then compared using a confusion matrix and accuracy could be identified. The AirSAR DEM was visually compared with another provided by the USGS. The following table shows accuracy reached for the different classifications. Fusion will be applied at a later date.

TABLE I

CLASSIFICATION ACCURACIES FOR TRAFFICABILITY ASSESSMENT

Trafficability Criteria	HSI Avg. Accuracy	SAR Avg. Accuracy
Vegetation	84%	90%
Hydrology Network	84%	76%
Road Network	92%	53%
Soil	68%	87%
Obstacles	67%	50%

Based on ground truth maps generated from all 6 criteria, a trafficability map was generated. Here is a 1km x 1km sample.

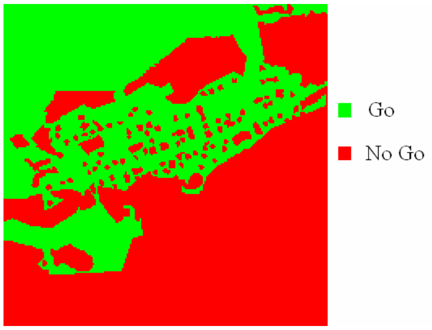

Fig. 3. 1km^2 Trafficability Map based on Ground Truth

VI. CONCLUSIONS AND SUGGESTED AREAS OF DEVELOPMENT

A. *Conclusion*

Using simple classifiers, SAR data added little information to the classification done on HSI data for hydrology and transportation networks. We can explain this situation by the fact that roads, rivers and some terrain all have smooth surfaces and are difficult to discriminate because they are all producing low backscatter energy. As expected, the HSI was able to identify hydrology and transportation networks within acceptable percentage of accuracy. The major contribution of SAR resides in the DEM production which can't be produced with HSI data. Also SAR displayed better results for vegetation classification than HSI although both can be considered as acceptable classifiers. The only objects detected and therefore considered obstacles in the studied data sets were buildings. They were difficult to identify as they were mingling with neighboring roads in the HSI data set due to high reflectance that was saturating pixels. SAR also displayed very poor accuracy rate due to high returns coming from neighboring trees. Soil classification showed a good average accuracy rate with SAR and a poor one with HSI. This situation can be explained by the fact that in the studied data set bedrock soil is mostly associated with mountains and clay with plains and SAR can discriminate terrain slope with ease.

It seems that strict decision level fusion doesn't take full advantage of the complimentarity of HSI and SAR and will offer lesser accuracy rates. More flexible fusion combined with a good understanding of the phenomenology produce better results, however will require more work from the user.

The other three polarizations not provided for the C-band seem to be particularly missing as best performing SAR classifications were realized in majority of the time with the C-V-V band.

B. *Suggested Areas of Development*

It would be interesting to investigate more complex classification techniques using SAR as classification proved to be particularly difficult with the data set using simple classification techniques. Pixel and feature level fusion should be investigated, as it has potential to improve classification.

REFERENCES

[1] R. Slocum, J. Surdu, J. Sullivan, M. Rudak, N. Colvin and C. Gates, "Trafficability Analysis Engine," CrossTalk, The Journal of Defense Software Engineering, pp.28-30, May 2003.

[2] U.S. Army, "Terrain Analysis," Field Manual 5-33, July 1990, Washington, D.C..

[3] F. Henderson and A. Lewis, "Principles & Applications of Imaging Radar, Manual of Remote Sensing" American Society for Photogrammetry and Remote Sensing, third edition, Vol. 2, chap 9 & 15, pp. 435-501& 733-763, 1998.

[4] V. Kerbaol and F. Collard, "SAR-Derived coastal and marine applications: from research to operational products," IEEE journal of Oceanic Engineering, Vol. 30, Issue 3, pp. 4-18, July 2005.

[5] M. Lewis, "Disriminating vegetation with hyperspectral imagery – what is possible?", Proc. of IEEE Int. Geoscience and Remote Sensing Symposium (IGARSS'01), Vol. 6, pp. 2899-2901, 9-13 July 2001.

[6] R. Pope and E. Fry, "Absorption spectrum of pure water," Journal of Applied Optics, Vol. 36, Num. 33, pp. 8710-8723, Nov. 1997.

[7] HyVista Inc., "HyMap Data Products", 2005

[8] A. Chu, "AirSAR Integrated Processor Documentation, Data Formats". Version 0.17, NASA JPL, June 9, 2003.

[9] J. Richards and X. Jia, "Remote Sensing Digital Image Analysis, an Introduction," Springer, third edition, chap 8, pp. 181-214, 1999.