Classification of urban SAR imagery using object oriented techniques

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***Abstract*—This paper describes the development of techniques for the production of urban mapping data from interferometric polarimetric synthetic aperture radar (SAR) data. The information contained in the radar data originates from four types of data properties:**

- **Radiometric, i.e. the channel intensities**
- **Polarimetric, e.g. decomposition properties entropy and alpha**
- **Interferometric, e.g. coherence and interferometric height**
- **Geometric, e.g. shape and area**

A multi-scale analysis, using the infrastructure provided by eCognition image analysis software, enables these different sources of information to be brought together. Ambiguities that result from the use of radiometric and polarimetric information alone are eliminated. A map product with broad classification information is produced. Validated results for urban scenes are presented, that were produced using data from the Deutsche Luft und Raumfahrt system E-SAR.

Keywords - SAR; urban; mapping; polarimetry; interferometry; object oriented image classification

I. INTRODUCTION

Synthetic aperture radar (SAR) provides a reliable means for the collection of imagery for mapping purposes, as the quality of the imagery is virtually unaffected by cloud cover. The objective of the research described here, is to assess the information that can be derived from interferometric fully polarimetric SAR data, for the production of urban maps. Techniques to determine urban classes have been developed using eCognition. This paper describes theses techniques and presents data on validation of the resulting product.

II. THE DATA

A. Airborne SAR Data

The airborne SAR data was acquired over the town of Farnborough UK, using the DLR E-SAR platform, in June 2000. This scene contains high and low density residential areas; light industry; an airfield; several lakes; woodland and major and minor roads. Complex data in the HH, HV and VV polarisations were acquired following 3 tracks in each of the East-West and North-South directions. Two passes in each direction were flown over the same track, whilst the third was offset by approximately 20m to allow interferometry. Resolution of the imagery is approximately 2m by 0.6m in ground range and azimuth respectively.

B. Map Data for Validation

In order to validate the image classification, broad classes were obtained from Ordnance Survey 1:25,000 map data. The classes included water; roads; buildings; trees; grass and railways. The 1:25,000 map shows a level of detail down to individual buildings. Whilst the building outlines themselves are somewhat generalised, it was felt that this scale of map was most appropriate for testing the airborne SAR data as there is a reduction in resolution of the interferometric and polarimetric SAR data due to the required pre-processing.

III. DATA PRE-PROCESSING

A. Coherence Generation

Interferometric coherence was generated from the pairs of tracks with a 20m baseline for each polarisation to give VV, VH and HH coherence. Additionally, the minimum, maximum and range of coherence were calculated from all three polarisations taken together.

B. Polarimetric Decomposition

The complex SAR data was decomposed into alpha, entropy and anisotropy using the techniques described in [1].

IV. OBJECT ORIENTED IMAGE CLASSIFICATION

To perform classification fuzzy membership classes were defined within the eCognition software.

A. Image segmentation

The input datasets were first segmented to introduce geometric features, such as area of object, which can be of use in refining the classification process. A multi-scale analysis of the data was conducted by segmenting the data at three different levels. The initial level-1 segmentation creates many small objects often of just a few pixels in extent. This maintains the finer features of the scene and is particularly useful for defining the road and building structure of a complex urban environment.

Higher levels progressively create larger objects that are groups of the objects in the preceding lower level. These larger objects can be used to group areas of similar small objects into new aggregated classes, such as 'urban area' or they can be used as masks to allow specific classification techniques to be run on only portions of the scene.

B. Available Features

As well as standard channel feature types (i.e. amplitude, coherence, alpha, anisotropy and entropy), the following features were found to be useful in discriminating between classes in the urban environment:

- Weighted polarimetric sum, which is a function of the three amplitudes HH, HV and VV and is defined as $1000\left(|HH|+|HV|+|VV|\right)^{0.001}$;
- Maximum coherence;
- Object size;
- Number of sub-objects from lower segmentation levels.

First the classification hierarchy was defined and validated on a dataset from the East-West data. Then the same hierarchy was applied to the North-West dataset. This type of analysis should give an indication of the sensitivity of the classification to:

- the feature membership function;
- scene dependent parameters;
- look direction or viewing angle of the sensor.

The look direction is particularly important for the discrimination of buildings as their signatures are strongly dependent on the direction of radar illumination.

V. CONSTRUCTING A CLASSIFICATION HIERARCHY

The classification hierarchy begins by splitting the scene into two classes, rough and smooth surfaces that are characterised by the weighted polarimetric sum. Smooth surfaces have characteristically low weighted sum values. The smooth surfaces are then further subdivided into the classes water, grass, runway and "other". The water class is defined by coherence, this will be low as it is a dynamic surface.

The classes grass and road are difficult to separate. One feature of the Farnborough image is the airport. This is separated out first as a relatively large object with a smooth surface, and then sub-divided into grass and runway, again by using coherence. In the non airfield smooth objects, there is some confusion between grassy areas such as playing fields and roads, but the main linear road features are maintained in the classification. The latter is an important point if human interpretation of the classified image is a requirement.

The rough surfaces are subdivided into trees, manmade (buildings) and medium vegetation classes. Polarimetric decomposition plays a greater role in the discrimination of rough surfaces than smooth surfaces. Trees are first extracted using high values of the inverse of the anisotropy*coherence. Of the remaining rough surfaces, the building class is characterised by low entropy and all other areas are assumed to be medium vegetation.

VI. RESULTS

A. East-West Pass Classification

The East-West data was classified first and the resulting classification is shown in Fig. 1. The overall road structure of the scene has been well maintained in the classification and the distribution of the buildings is reasonably consistent with the Ordnance Survey map shown in Fig. 2. Features of the classification include:

- The confusion of short grass on playing fields with tarmac;
- The clarity with which the bow shaped housing estate (marked in Fig. 1) shows up. It is thought that this is due to a combination of the housing estate being newer than its neighbours with less mature vegetation, and the denser nature of the buildings, seen also in Fig. 2.

Figure 1. Classification result for East-West pass. Arrow points to well detected housing estate

B. Validation

Classified data was exported and manually georectified using a second order polynomial warp to the Ordnance Survey 1:25,000 map data.

A confusion matrix, shown in Table 1, was generated to compare the classified SAR data with the validation data, using a sub set of the derived classes. This table shows that a user of the classified map could be reasonably confident of the "Building" class but less confident in the classes 'Trees' and 'Smooth surfaces'. A certain amount of this confusion may be due to the interaction of trees and other vegetation with neighbouring buildings. Some of the buildings are partially incorrectly classified due to signature variations over the building.

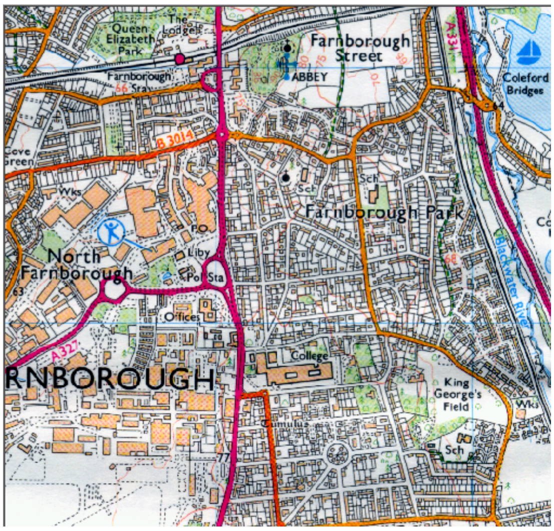

Figure 2. 1:25000 Ordnance Survey Map of Farnborough area for comparison. © Ordnance Survey 2003

TABLE I. CONFUSION MATRIX: EAST-WEST SAR CLASSIFICATION VS. 1:25000 MAP DATA. SMOOTH SURFACE CLASS CONSISTS OF ROADS / TARMAC AND OPEN GRASS

		Reference Class			
	Class	**Trees**	**Building**	**Smooth surface**	**User accuracy (%)**
SAR Classification	**Trees**	158461	105134	53932	**49.9**
	Building	10357	214373	40873	**80.7**
	Smooth surface	58088	205604	554155	**67.7**
	Producer accuracy (%)	**69.8**	**40.8**	**85.3**	66.1

C. North-South Pass Classification

The North-South data was classified using the hierarchy built with the East-West pass, although some adjustment of the threshold values used in the membership functions was necessary. The resulting classification confusion matrix is shown in Table II. Overall it is similar to that of the first classification result, with the exception of the tree class.

TABLE II. CONFUSION MATRIX: NORTH-SOUTH SAR CLASSIFICATION VS. 1:25000 MAP DATA. SMOOTH SURFACE CLASS CONSISTS OF ROADS / TARMAC AND OPEN GRASS

		Reference Class			
	Class	**Trees**	**Building**	**Smooth surface**	**User accuracy (%)**
SAR Classification	**Trees**	114159	64459	38081	**52.6**
	Building	22628	234517	37419	**79.6**
	Smooth surface	78315	251504	577618	**63.6**
	Producer accuracy (%)	**53.0**	**42.6**	**88.4**	65.2

D. Combined Classification

Figure 3 shows the improvement in the classification of buildings achieved by combining the information acquired from different look directions. Note also the roof structure visible in the left hand building in the top right image.

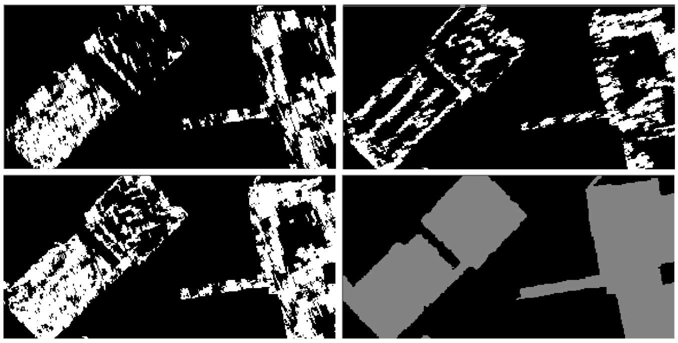

Figure 3. Classification comparison. (top left) East-West pass, (top right) North-South pass, (bottom left) Combined building class, (bottom right) Reference data

This combination of the two image classifications obtained an improved classification with a new overall accuracy of 71.9%. The producer accuracy of the new combined building class increased to 62.1% highlighting the importance of the combination of data acquired from multiple look directions for the correct classification of 3D features. The producer accuracy for the tree class remained stable at 62.7% whilst the smooth surface class reduced slightly to 82.6%.

VII. CONCLUSIONS

The use of both fully polarimetric and interferometric data together is useful for image classification. However it is also necessary to derive additional features from the data, on shape and size, to resolve ambiguities between some classes. Discrimination of the class 'Buildings' is particularly difficult, due to the variations over a single building signature caused by building and roof structures, the interaction with neighbouring or overhanging vegetation, and the effect of viewing direction.

The combination of information from more than one look direction can improve the overall classification. However, currently some threshold parameter adjustment is necessary to obtain the best results from the classification hierarchy for each image acquisition.

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REFERENCES

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