USING BACKSCATTER FROM RADAR IMAGES FOR CLASSIFYING AND DETERMINING THE BULK DENSITY OF THE URBAN ENVIRONMENT

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Commission VII, Working Group 9

KEY WORDS: Land_Use, Urban, Classification, Radar

ABSTRACT

The urban environment is a mixture of buildings (of varying size, shape, and density), and vegetated and non-vegetated open spaces. The proportion of each of these characteristics in an area is generally related to its land use. Radar is showing potential in assisting classification of the built environment due to its close correlation with the bulk density of buildings. However one of the problems with using radar is that the backscatter is particularly sensitive to the radar look direction with respect to street orientation. This paper examines this property, and how different aspects of radars interaction with the built environment can assist in urban classification.

INTRODUCTION

There is a need to classify the environment into its various land uses to keep records of a cities size and layout. Some cities in developing countries are growing rapidly, making it difficult for governments to maintain these records by conventional surveying and mapping methods. Satellite and airborne radar remote sensing provides a relatively cheap and fast method of acquiring up-to-date information about the environment, especially in regions where cloud and rain may affect visible and infrared sensors. Radar images give detail about the shape and physical properties of the earth's surface, and are showing potential for determining the vertical bulk density (as compared to planimetric density from visible/infrared sensors) and for the classification of the urban environment into its various land uses.

Although there has been a substantial amount of analysis done on radar and the environment, very little has concentrated on the urban environment alone. Bryan (1982) and Hardaway et al (1982) have analysed radar backscatter with respect to urban street orientation and showed a strong correlation. Henderson (1985) carried out a detailed study using dual-polarised Synthetic Aperture Radar (SAR) to classify the urban environment, but found the radar had some confusion between classes. Deguchi et al (1995) examined the relationship between building coverage ratio, from visible/near infrared images, and bulk ratio of urban environments, using radar data. Forster et al (1996) have also investigated the possibility of combining visible/near infrared data of a city, with radar information.

Single polarised data provides limited information compared to multipolarised images. Some work has been undertaken on quad-polarised radar and polarisation signatures, using them to distinguish between urban, park, forest, geology, and ocean. (See for example, Evans et al (1988), Van Zyl et al (1987), and Zebker et al (1987)). These studies looked at the urban environment in a broad sense rather than classification of the built environment into all its land uses. A detailed study of the types of scattering in the urban environment from multipolarised radar by Dong et al (1996) has shown some promising results.

The present study involves examining radars interaction with the urban environment so that information about land use and the bulk density of the urban area can be derived from radar images. The bulk density is related to the volume of buildings in a particular region. For example a central business district has a higher bulk density than a residential area. An initial investigation looks at the relationship between radar backscatter and urban land use classes (obtained from a SIR-B image over Sydney, Australia). A model has been developed to give the expected radar backscatter from a block of buildings, and its results are also presented.

RADAR BACKSCATTER IN THE URBAN ENVIRONMENT

Radar transmits a wave of known length, polarisation, azimuth direction, and incidence angle. The built environment has properties, such as building size, shape, orientation with respect to radar, and material (surface roughness and dielectric properties including moisture content), with which the radiation interacts, and determines the properties of the backscattered radar response. Radar is particularly sensitive to building "bulk" and the orientation of buildings with respect to the radars look direction.

One of the main contributions to radar backscatter in the urban environment is due to corner reflections. Double bounce corner reflection, or dihedral reflection, occurs when the radar look direction is perpendicular to a building wall. The radar wave will bounce from the ground to the wall and back to the sensor, or vice versa.

RELATIONSHIP OF LAND USE AND RADAR BACKSCATTER

A preliminary study has been undertaken which involved examining SIR-B data (L-band, HH) over a region in the city of Sydney, Australia. The chosen area had a mixture of residential, commercial, and industrial land uses. The study involved obtaining pixel values over a number of residential, commercial, and industrial areas of varying street orientation with respect to the radar azimuth angle. The average pixel values and standard deviations were then calculated for the subject areas. Although the sample size was small, there was a definite trend showing a correlation between radar backscatter and building size.

The results show that the average pixel value and standard deviation for the residential classes were lower than those of the commercial classes while the industrial areas had the highest values (for their relative orientation angles). It is expected that residential land use would have the lowest average pixel value and standard deviation since residential buildings are generally smaller in size (therefore less area to backscatter the radar wave). The residential building materials were mainly brick or fibrous cement walls with tiled roofs. These are primarily dry with a low dielectric constant. A low dielectric constant means a large amount of the radiation will penetrate the surface of the building reducing the backscatter measured at the radar receiver.

Areas of commercial buildings are usually more dense and variable than residential. A local shopping area often has metal clad roofs and terrace type buildings. A central business district (CBD) contains many large buildings, both in floor area and height, with a high density. There are more metal structures (having a high dielectric constant and therefore a strong reflection) acting as support in large buildings. Hence areas of commercial buildings show higher average pixel values and standard deviation, than residential classes.

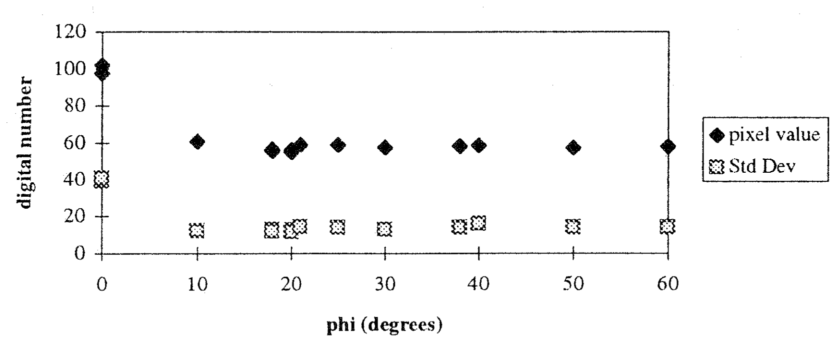
Industrial buildings gave the largest average pixel value and standard deviation. Industrial regions consist of large buildings mostly clad in metallic materials. Metals are conductors with a high dielectric constant. They can give a very strong backscatter at particular orientation angles. The residential class, with the largest sample size of the three, was examined further to show a relationship between the backscatter response (being directly related to the pixel value, or digital number, on a radar image) and building orientation with respect to radar direction (Figure 1). The standard deviation was also determined. When the angle between the normal to the street or building and the radar look direction (phi) is equal to zero, the backscatter response is at its highest. As phi increases to around 22^0, the backscatter decreases to a minimum. For values of phi above 20 degrees the backscatter varies little with phi. This result is similar to that obtained by Hardaway et al (1982).

A MODEL FOR PREDICTING URBAN CHARACTERISTICS

A model has been developed to give the expected backscatter from a group of buildings of user defined size (single or multiple storey), shape, material (including surrounding ground surface), and radar parameters. Existing formula, giving the backscatter for a corner reflector and a rectangular facet, have been adapted into the model. It is presently designed for a simple building of rectangular shape with either a flat or sloping roof. When the model is used to find the expected backscatter from a block of buildings, of either small residential size or large commercial size, the roof facing the radar, and the corner reflector effect from the front wall, are the dominant contributors to the backscatter (Figures 2 & 3). Figures 2 and 3 show an example of the simulated backscatter with respect to phi (for residential and industrial areas respectively) for each component of a building, as well as the total backscatter. The oscillations of the backscatter for both buildings are due to difference in phase as the distance the wave travels between the extremes of the object leads to either constructive or destructive interference. These oscillations become more frequent as building size increases.

As expected, Figures 2 and 3 show the backscatter is greatest when the radar approaches the building normal to the wall (when phi equals zero). The backscatter drops as phi increases to 45^0 (with predominantly diffuse backscatter). Around this angle the backscatter response from trees (essentially volume scattering) need to be considered.

Figure 1. Average pixel values of SIR-B vs Orientation angle (Residential class)



For industrial regions, which contain buildings mostly clad in metallic materials, the slope of the roof will also be important. If the roof is positioned such that the radar is incident perpendicular to the surface the radiation will be reflected directly back to the antenna. The radar backscatter will be exceptionally high due to the roofs high conductivity.

POLARISATION SIGNATURES IN THE URBAN ENVIRONMENT

Multipolarised radar provides much more information than individual cross or co-polarised radar. The polarisation signature shows the co-polarised or cross-polarised backscatter received as a function of the radars transmitting polarisation. The polarisation of a wave can be described by its ellipticity and orientation angle (Ulaby and Elachi, 1990). The ellipticity describes the flatness of the ellipse, from a line (where the ellipticity angle is 0^0), to a circle (ellipticity angle is 45^0). The orientation angle describes the orientation of the major axis of the ellipse with respect to the horizontal. For example, a plane polarised horizontal wave would have an ellipticity of 0^0 and an orientation of 90^o, while a circularly polarised wave would have an ellipticity of 45^0 or -45^0 and an orientation between -90^0 and 90^0.

A polarised wave may also be described as containing a vertical and horizontal component separated by a phase difference. A perfectly conducting dihedral corner reflector (Figure 4a) undergoes a phase shift of 180 degrees during reflection, whilst a smooth flat surface undergoes almost no phase shift. These are commonly termed double and single bounce, or even and odd bounce scattering mechanisms.

The polarisation signature contains valuable information for determining the characteristics of a surface. Trees, for example, can give a high cross-polarised response which may help distinguish between some residential and commercial classes since residential areas are more likely to contain a higher proportion of trees (both in gardens and along roads).

Figure 2. Simulated Backscatter from Components of Residential Building with respect to Radar Look Direction.

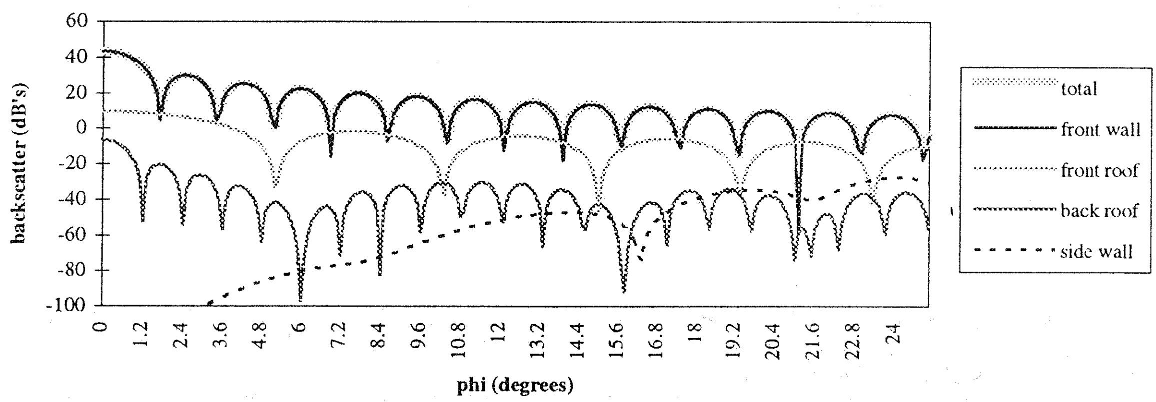


Figure 3. Simulated Backscatter from Components of Industrial Building with respect to Radar Look Direction.

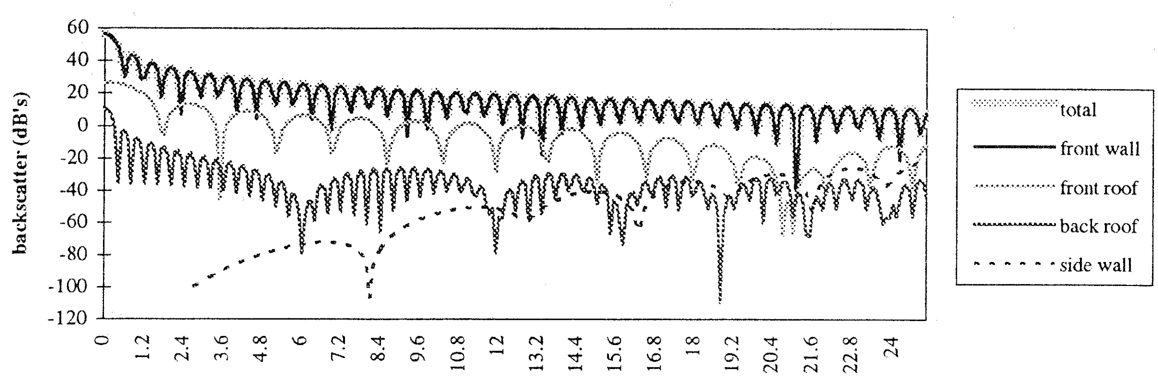


Figure 4a. Co-polarisation Signature of a Perfectly Conducting Dihedral Corner Reflector.
Figure 4b. Co-polarisation Signature of the Central Business District of Sydney, Australia.
Figure 4c. Co-polarisation Signature of a Residential Area of Sydney, Australia (Radar Incidence Angle $=60^0$).

Figure 4a.

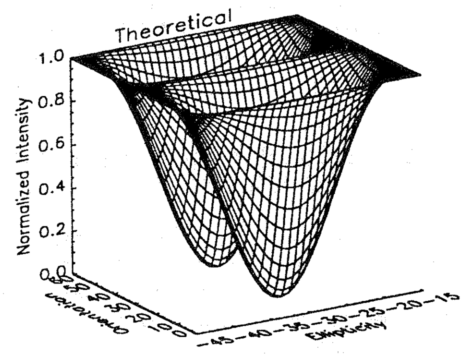


Figure 4b.

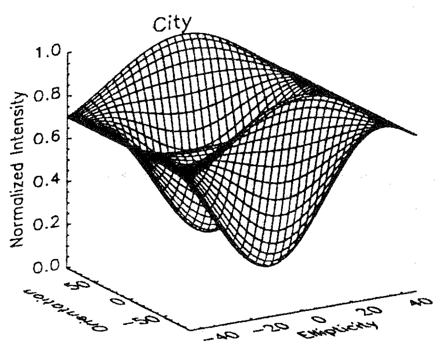
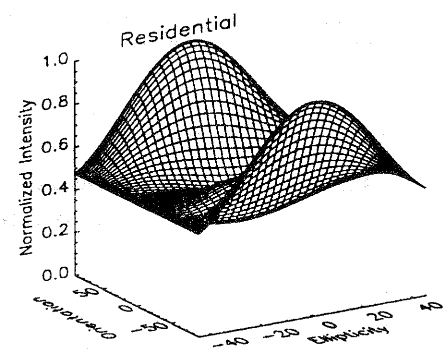


Figure 4c.



A polarisation signature of the central business district (CBD) of the city of Sydney, Australia, is shown in Figure 4b. This area consists of large dense buildings, and the radar look direction is approximately normal to these buildings. There is little else in this region (no parks or open space) hence the dominant reflection is from the dihedral corner reflector effect. It should be noted that the pedestal (the vertical distance between zero and the minimum backscatter value) of this polarisation signature is low, implying that there is little diffuse scattering (which one would expect from vegetation). Although the residential area is a mixture of buildings, trees, and parks, the dihedral corner reflector effect is still distinguishable in its polarisation signature with the two peaks showing, but it has a higher pedestal than the city (Figure 4c).

SUMMARY AND CONCLUSION

Unfortunately real urban data is not as easy to predict as a simple square building. Not only are there dihedral corner reflector effects (as in the rectangular building above), but there will also be multiple bounce effects from surrounding buildings and other structures. Single bounce effects, from a flat surface near normal to the radar look direction, also provide a large backscatter response. In addition, phase interference effects can occur causing a larger or smaller backscatter than expected. These effects are related to building size.

Radar backscatter is a function of many factors in the urban environment, the dominant ones being street orientation with respect to the radar look direction, and building bulk. A thorough understanding of these dominant backscattering contributors in a real urban situation is necessary to enable all factors to be incorporated when determining the land use and bulk density of the built environment. Further research needs to concentrate on multipolarised data and its combination with visible/near infrared images, as this may provide extra information to enable an accurate classification of the urban area.

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