Generation of synthetic millimetre wave radar images of complex urban areas

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Abstract: Interpreting radar imagery of very cluttered urban areas is challenging. For example, imagery is subject to effects such as layover distortions due to the height of buildings and also considerable radar shadowing. In this paper the use of synthetic imagery to capture the key elements of radar imagery is examined. The real-world millimetre wave imagery can then be related to the physical models from which the synthetic imagery is generated leading to improved scene understanding. This paper describes the modelling process adopted and compares real-world imagery from a 35GHz millimetre wave radar with the synthetically generated imagery using an example urban area.

1 Introduction

Although high spatial resolution radar imagery contains a large amount of information, it has significantly different properties from electro-optic imagery and is less intuitive to understand, particularly in the case of forward looking millimetre wave radar imagery. Artefacts arising from the coherent nature of the imaging process further complicate the easy interpretation of radar imagery of complex urban scenes.

To aid interpretation of such imagery, this paper considers the utility of simulated radar imagery which is derived from three dimensional models of the actual scene via a radar simulator. Synthetic imagery is presented and compared with real-world 35GHz radar imagery.

2 Radar Imaging and Modelling

In this section, a brief overview of the radar imaging system is given. This is followed by an overview of the modelling approach adopted to produce synthetic radar images.

2.1 Imaging

QinetiQ employs a 35GHz radar system which has been jointly developed with MBDA UK limited as an airborne imaging radar. The images generated are formed using an enhanced form of Doppler Beam Sharpening (DBS) in which a number of focussed synthetic apertures are formed and subsequently combined to form a larger image.

This section describes briefly how the distorting features arise in the 35 GHz forward looking DBS images together with example imagery. A brief description of the radar and scattering model used is also given.

2.1.1 Doppler Beam Sharpening

A typical DBS imaging radar operating at 35GHz can provide cross-range resolutions down to 0.5m at ranges of a few kilometres. Better resolutions are attainable by increasing the Fourier processing time and this can be achieved in practice through staring the beam or increasing the beamwidth in a scanning system. The cross-range resolution is achieved through suitable Fourier processing which exploits the Doppler variation across the radar footprint. High down-range resolution is achieved through the use of high bandwidth waveforms, which routinely provide resolutions of 0.25m. The result of this process is a two dimensional range-Doppler map of the illuminated area of ground. A swath is formed by scanning the radar footprint, resulting in a number of range-Doppler maps which are placed together to form the complete image.

Initial focussing using inertial measurements produces reasonably well focussed range-Doppler maps. These are then subjected to data-dependent focussing techniques to compensate for unmeasured motion of the airframe, in particular acceleration components along the radar line of sight [1].

Figure 1: Photograph of a storage facility.

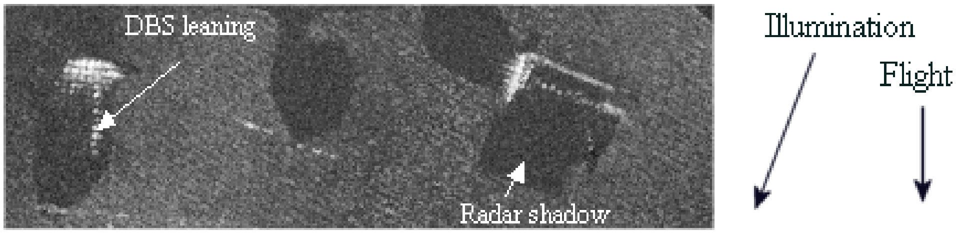

Figure 2: 35 GHz radar image of two storage facilitiues showing shadowing and leaning.

Range-Doppler maps are transformed into ground pixels via the appropriate transform, based on inertial instrument information such as velocity and height. Registration techniques are used to aid the assembly of the complete image, ensuring good alignment between individual range-Doppler maps. This process results in a plan view of the ground at a known scale.

2.1.2 Features of DBS

Shadows are common place in radar images and are caused by the presence of a tall structure interrupting the radar's beam. As an example, consider the storage facility shown in figure 1. An example of radar shadow caused by one of these buildings can be seen in figure 2. Shadows of isolated objects can provide a useful aid in detecting the presence of building structures and can also be used to provide information about the height of the structures. However, complex built up areas result in many shadows which can obscure elements of the scene and contextual features such as roadways, so complicating interpretation of the scene.

DBS makes the assumption that the scene being imaged is flat, thereby simplifying the mapping of the range-Doppler measurements onto a nominal ground plane. This assumption of flatness allows the imagery to be thought of as if it were a plan view of the scene. However, real scenes are rarely flat, especially complex urban environments where there may be a number of large vertical structures of various heights. This height extent minimises the line of sight depression angle to the radar, thereby increasing the measured Doppler whilst simultaneously reducing the measured range. This change in the measured parameters causes a vertical structure to appear to lean toward and perpendicular to the direction of flight.

As an example of leaning in radar images, consider the storage facility shown in figure 1. Note the numerous metallic pipes which run down the centre of the roof of the building. Now, consider the radar image of two storage facilities shown in figure 2. The top pipes on the building to the right of the image appear to be running down the centre of the structure. This is expected as this particular building is imaged with the radar travelling in a direction which is roughly down the page. The pipes therefore all lean toward and perpendicular to the velocity vector but, due to the relative orientation of the building, still appear along the building's major axis. The building to the left of the image is subjected to a similar leaning effect but due to its orientation, this effect is immediately noticeable with the vent pipes appearing out of position relative to the centreline of the building.

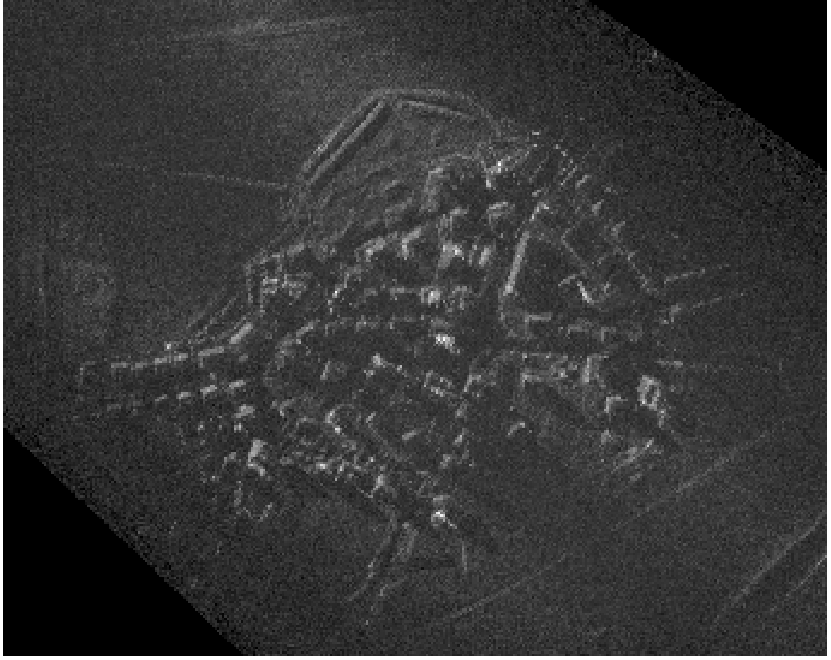

Figure 3: 35GHz radar image of a typical rural village.

2.2 Modelling

The generation of synthetic imagery requires two elements; a model of the scene to be imaged and a model of the scattering processes/processing by the radar. The approach adopted is to use a simple scattering/radar model that combines an empirical characterisation of the scene reflectivity with a simple geometrical representation that accurately captures the projections of the 3D geometries on to 2D images. The fundamental question then is how much detail needs to be included within the 3D model of the scene and the empirical scattering models used to allow a sufficient representation of the scene?

2.2.1 Scene representation

The composition of a scene can range from a simple user defined building in the middle of flat land to a more complex scene built using Digital Terrain and Elevation Data (DTED). The model also includes provision for the capture of trees and vegetation, which are modelled using a fractal height model to produce realistic image texture including shadowing effects.

2.2.2 DBS effects

The DBS induced features are simulated within the radar and scattering model used. Since the model is geometry based effects such as radar shadowing and height induced leaning are inherently modelled.

3 Results

In this section the synthetically generated radar imagery is compared with actual 35GHz DBS data to assess the suitability of the simulated scenes for image registration. For this, a DBS image of a suitable village in the UK was chosen.

The layout of the village is centred around a cross roads with a church, school, shop and farm complex near the village centre and roads radiating outwards to more modern developments on the outskirts of the village. In total, there are approximately 100 buildings, of varying shapes and sizes, very compactly located within about a 500m by 500m area. A 35GHz radar image of this village is shown in figure 3. Although the image appears quite cluttered, it is possible to pick out various features such as roads and

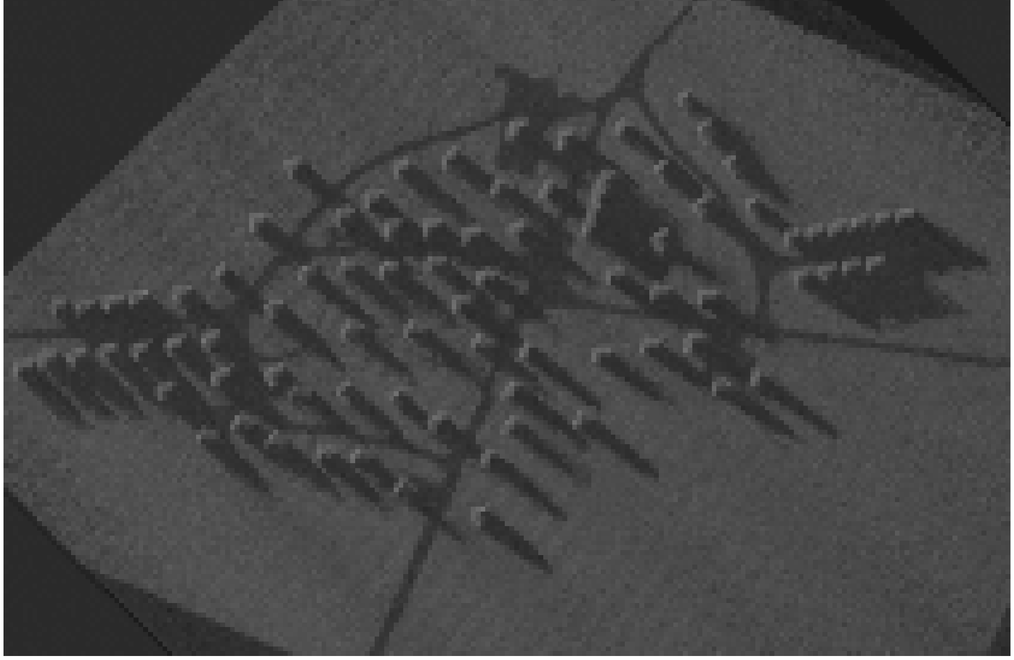

Figure 4: Synthetic radar image of village generated using a simple 3D model.

building shadows. The road may not always be visible though as radar shadows from buildings may obscure it depending on the viewing geometry. Accurate ground truth information may not always be available so, in this example, a model of the village is constructed using a simple 3D representation of the buildings. The final synthetic image is shown in figure 4. Although the synthetic image isn't an exact reproduction, on visual inspection it is possible to associate objects between the two images, using the position of the buildings and also the road structure that is visible.

4 Conclusions

In this paper, it has been shown that synthetic radar images can be generated using very simple 3-D models. Complex scenes, such as the village, used as an example, can therefore be developed very rapidly using simple building blocks.

Using only a simple model, a fair representation of the scene is possible with buildings appearing in the correct position which is expected to permit accurate image registration. This is a useful result since highly detailed 3D models of urban areas may not always be available or may take too long to generate.

Acknowledgments

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References

[1] C. Oliver and S. Quegan, *Understanding Synthetic Aperture Radar Images*, Artech House, London, 1998.