Three-Dimensional Multiple Layer Extended Target Modeling for Inverse Synthetic Aperture Radar Studies in Target Identification

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Abstract

For the target-sensor simulation involving a ship and a High Range Resolution (HRR) radar system the target model has to have physical extent greater than the radar's resolution abilities. In this paper an extended single layer and its enhanced multiple layer multiple scatterer mathematical model counterpart are presented. Simulations illustrate the compliance of the target model to the theoretical foundations and practical findings of Inverse Synthetic Aperture Radar (ISAR) imaging and its further applications to automatic non-cooperative target classification and identification issues.

Keywords: High Range Resolution Radar Systems, Inverse Synthetic Aperture Radar, Mathematical Modelling, Extended Target

1. Introduction

ISAR systems are employed in long-range imaging and probable classification and further positive identification of non-cooperative and stealthy extended targets. Extended targets are objects that have greater physical dimensions than the radar sensor's resolution abilities. Therefore the sensor can distinguish many features of the target instead of presenting it to the radar operator like a single presence point.

In this paper a three-dimensional multiple layer extended target model as viewed by an Inverse Synthetic Aperture radar system emulator is studied. The application under consideration deals with the detection of numerous high reflectivity features on the illuminated object on the basis of multiple superstructure layers as opposed to only the highest or most dominant single reflector within the sensor's resolution cell ability [Emil et. Al. (1997)]. This method is used to simulate in a more analytical manner an extended target-ISAR system configuration emulation. An efficient method to implement such a model that is able to provide the corresponding range profiles (time - domain results) and Fast Fourier transformed duals (frequency - domain transforms) is by using database modelling for the afore-mentioned target sensor pair [Kostis et Al. (2005)]. Moreover the frequency domain results can be useful for automatic non-cooperative target classification and identification issues [Kostis et Al. (2006)].

Summarizing the contributions of this paper are the analytical representation of a multi-layer multiple scatterers model for the simulation of extended targets and the explanation of the corresponding data modelling specifics and processing results in order to support the simulation of a High Range Resolution Radar System.

Finally the paper is organized as follows : In Section 2 an introduction into database modelling for an extended target as applied to high range resolution radar systems simulation is given. In Section 3 the first instance of the model with only the highest scatterer dominant in a resolution cell is explained. Section 4 compares the first instance of the model to the other enhanced version which includes multiple height scatterers in the same *x* and *y* coordinates. In Section 5 results are presented that use the enhanced FFT outcomes in order to better identify the target. Finally in Section 6 recommendations for further work and concluding remarks are given.

2. Entity-Relationship Modelling for ISAR Processing

High Range Resolution Systems utilise numerous resolution cells that divide up the target into several blocks [Sullivan (2000)]. From each of these blocks information can be extracted that can tomographically describe the nature of the target. Particularly in a resolution cell the radar can resolve features that belong to the same *x* and *y* coordinates but have different height values. For the simulation of this situation a multiple scatterers target model, which is also called extended, is required [Chevalier (2002)]. The emulation of the afore-mentioned situation can be based on database modelling, using the entity-relationship model for the single layer target as shown in Figure (1) and the entity-relationship model for the multiple layer target as shown in Figure (2).

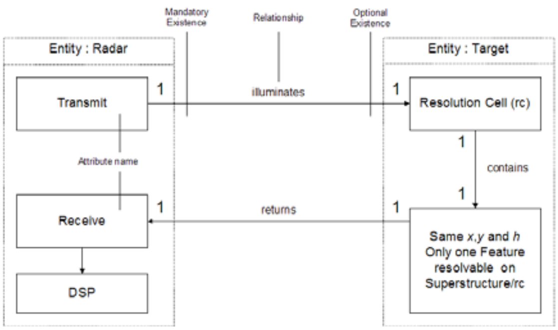

Figure 1. *Single Layer Model System Design*

The main difference is that in the first model only one return is received by the radar per resolution cell whereas in the second case there are multiple returns from the superstructure, always per resolution cell, since many reflectance points are simulated.

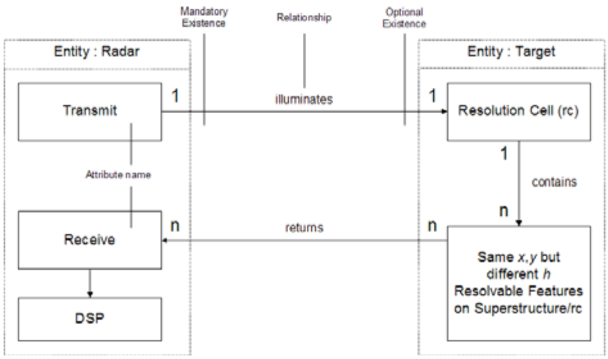

Figure 2. *Multiple Layer Model System Design*

3. Three-Dimensional Single Layer Extended Target Modelling

It is assumed that the radar sensor can divide the vessel into one hundred and forty-five (145) square equal cells. Each of these cells produces an echo back at the radar which is modelled as a complex number (amplitude and phase), as described in Equation (1).

$$Q(\boldsymbol{k}) = \int I(\boldsymbol{x}) \ e^{2(\boldsymbol{k}.\boldsymbol{x})j} \ d\boldsymbol{x} \quad \rightleftarrows \quad I(\boldsymbol{x}) = \int q(\boldsymbol{k}) \ e^{-2(\boldsymbol{k}.\boldsymbol{x})j} \ d\boldsymbol{k} \qquad (1)$$

Analytically each cell is characterised by a reflectance amplitude and an initial phase associated with the corresponding scattering point, as represented in Equation (2).

$$RESOLUTION \ CELL \ = \ Ae^{j\phi} \qquad (2)$$

where A is the Reflectance Amplitude and φ is the Reflectivity Initial Phase of the resolution cell on the target. All resolution cells form the complete reflectance model which is shown in Figure (3).

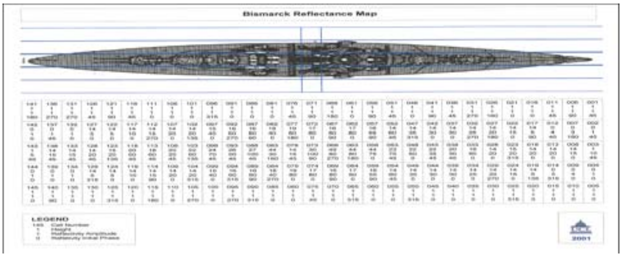

Figure 3. *KMS Bismarck - Single Layer Model*

4. Three-Dimensional Multiple Layer Extended Target Modelling

The enhanced model is presented in this section where there are numerous returns by each resolution cell. Analytically there are multiple scatterers at different height levels while on the same same *x* and *y* coordinates. For example, in the middle of the vessel the points *{(0,0,0)}* and {*(x1,y1,h1)}* are actually *{(0,0,0)}* and *{(0,0,h1)}*, as shown in Figure (4).

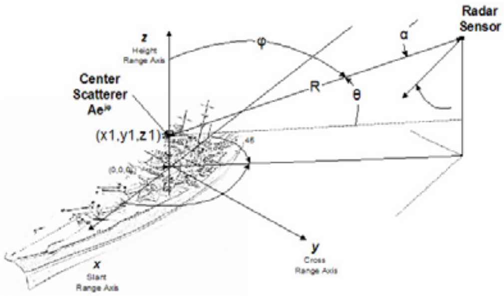

Figure 4. *ISAR observation of the multiple layer model*

Moreover additional scatterers have been added to the giant front and back gun turrets since they are bright electromagnetic energy scatterers. The complete multiple scatterers distribution at different heights is shown in Figure (5).

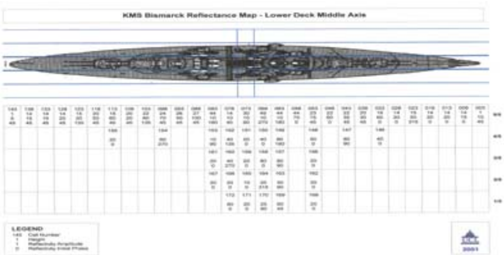

Figure 5. *KMS Bismarck - Multiple Layer Model*

5. Results

According to Inverse Synthetic Aperture Radar theory the digital signal processing of the target returns should result in the Slant Range Profiles (SRP) of the target. Especially when the roll motion of the target is taken mostly under consideration, the Slant Range Profiles will be able to provide the sea-level view of the target [Rihaczek (2000)].

5.1 Slant Range Profiles

The results of the simulation with the target in a dominant roll motion are as shown in Figure (6) for the single layer model and are as shown in Figure (7) for the multiple layer model. Both graphs agree with the theoretical and practical ISAR findings.

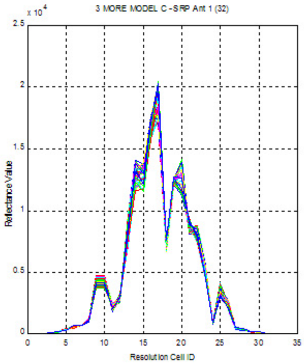

Figure 6. *Single Layer Model Slant Range Profile*

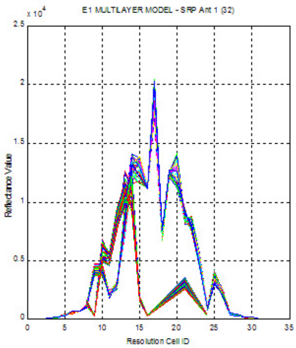

Figure 7. *Multiple Layer Model Slant Range Profile*

5.2 Doppler Processing

The Slant Range Profiles, which are obtained in the Time Domain (TD), are translated using a Fast-Fourier Transform (FFT) process into the Frequency Domain (FD) producing Figure (8) for the single layer target and Figure (9) for the multiple layer target. Both graphs agree with the theoretical and practical situations.

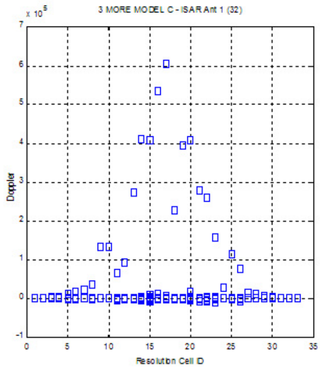

Figure 8. *Single Layer Model FFT Processing*

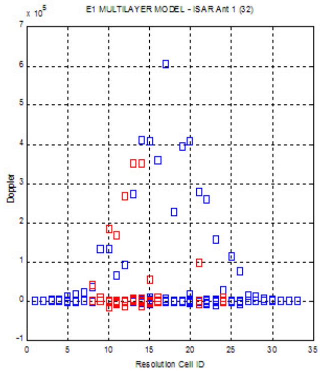

Figure 9. *Multilayer Model FFT Processing*

5.3 Classification & Identification Issues

The frequency domain results can be used for further classification and possible positive identification of the target at hand, although the latter can be proved to be an extremely difficult task. For the purpose of this simulation the enhanced model results can be used in order to find points of high reflectance on the target which can be attributed to radio or radar antennas, superstructure trihedrals and metal gun placements. Should a vessel database be utilised with the description of the ship's electromagnetic identity the collected information can be further given a classification tag, as shown in Figure (10).

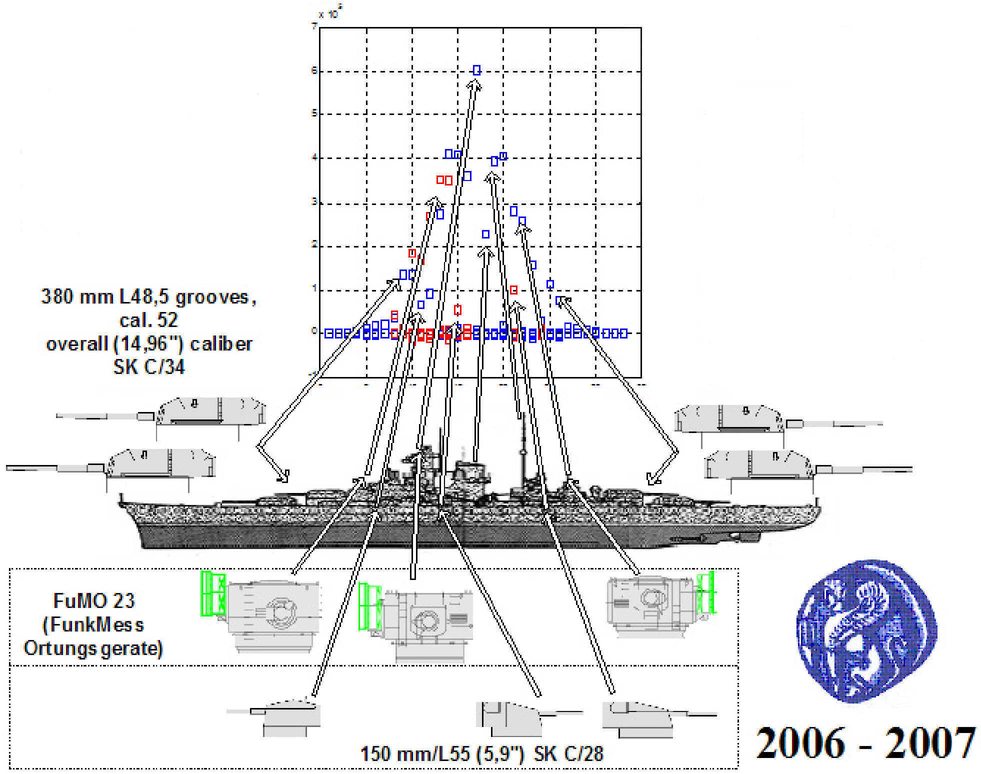

Figure 10. *ISAR Identification Results*

6. Conclusions

A multiple layer mathematical model for the simulation of returns by an extended naval target has been proposed. The simulation has been implemented while paying attention to the theoretical and practical findings and has been found to agree on all counts. Furthermore the performance of the frequency domain results have shown the ability to accommodate further target classification and identification possibilities.

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