TARGET RECOGNITION FOR ARTICULATED AND OCCLUDED OBJECTS IN SYNTHETIC APETURE RADAR IMAGERY[1]

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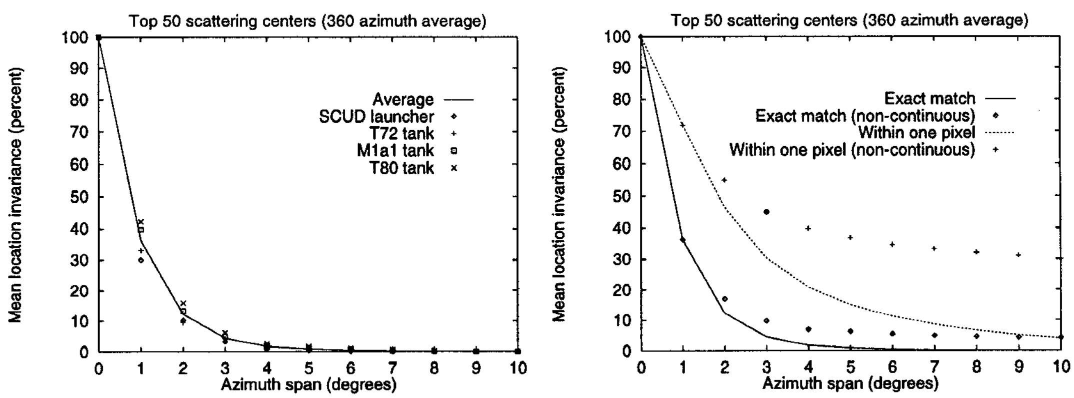
ABSTRACT

Recognition of articulated occluded real-world man-made objects in Synthetic Aperture Radar (SAR) imagery has not been addressed in the field of image processing and computer vision. The traditional approach to object recognition in SAR imagery (at one foot or worse resolution) typically involves template matching methods, which are not suited for these cases because articulation or occlusion changes global features like the object outline and major axis. In this paper the performance of a model-based automatic target recognition (ATR) engine with articulated and occluded objects in SAR imagery is characterized based on invariant properties of the objects. Although the approach is related to geometric hashing, it is a novel approach for recognizing objects in SAR images. The novelty and power of the approach come from a combination of a SAR specific method for recognition, taking into account azimuthal variation, articulation invariants and sensor resolution.

1.0 SCATTERING CENTER LOCATIONS

The relative locations of SAR scattering centers are related to the aspect and physical geometry of the object, independent of translation and serve as distinguishing features. Because our experimental data (using the XPATCH radar signature simulation code), Figure 1, shows that at six inch resolution significant numbers of these features do not typically persist over a few degrees of target rotation (even allowing for scintillation as in the 'non-continuous' results), we capture this azimuth variance by using 360 azimuth models. Other previous work [Ikeuchi,96] [Novak,94] [Novak,97] [Verly,93] has been limited to 12 to 72 models at 1 foot resolution, attempting to recognize unarticulated, unoccluded or slightly occluded objects. Here we demonstrate the need for 360 azimuth models at six inch resolution for recognition of articulated, highly occluded and occluded articulated objects. (While the target azimuth is uncontrolled, the radar depression angle to the target is controllable, or known, and is fixed at 15 degrees).



(a) Exact match invariance. (b) Average persistence.

Figure 1: Scatterer Location Persistence.

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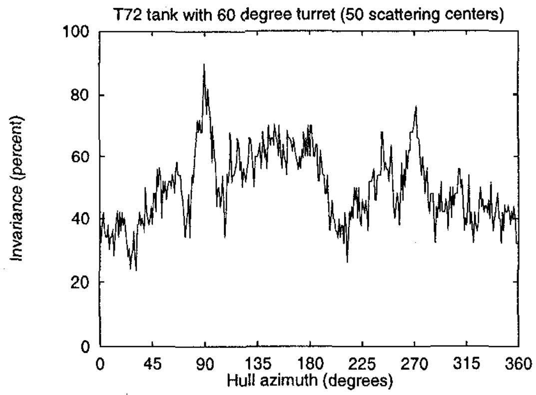
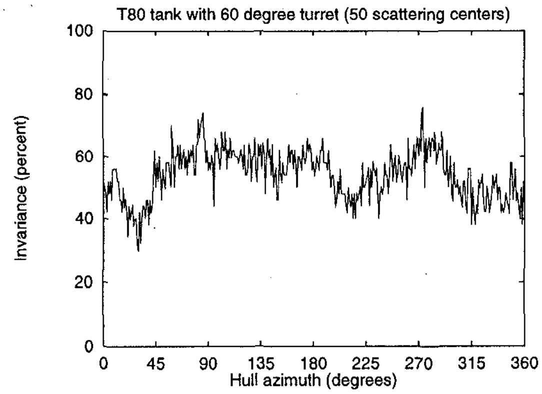
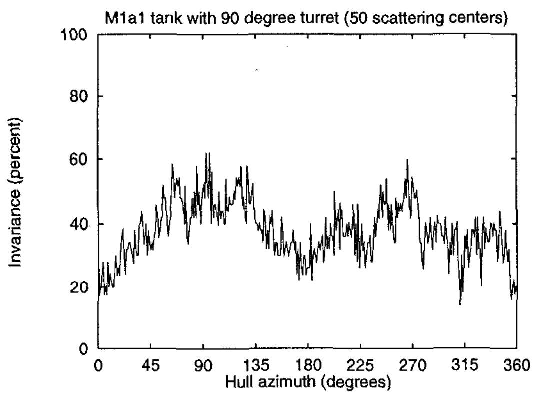


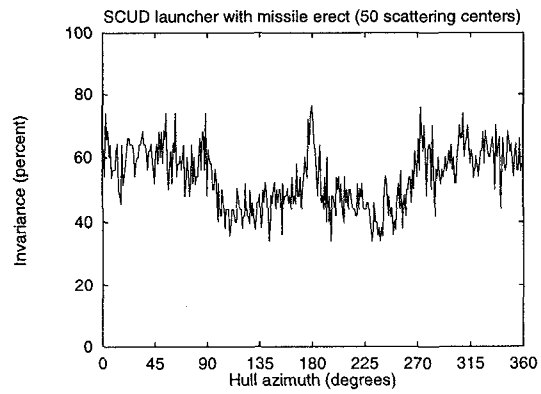
(a) T72 (60^o turret).



(b) T80 (60^o turret).



(c) M1a1 (90^o turret).



(d) SCUD launcher (missile up).

Figure 2: Articulation Invariance.

2.0 ARTICULATION INVARIANCE

Our approach is the first to postulate the existance, demonstrate and quantify articulation invariants in SAR images. In contrast to the large azimuthal variance, we find significant invariance with target articulation (i.e. turret rotation for the T72, T80 and M1a1 tanks; missile erect vs. down for the SCUD missile launcher). Some examples of articulation invariance are shown in Figure 2 (comparing articulated with non-articulated scatterer locations), where on average 47.9 percent of the scattering center locations are invariant with articulation of these objects. These articulation invariant features allow us to develop a recognition approach that avoids the combinatorial explosion that would accompany attempts to explicitly model articulation.

3.0 RECOGNITION ENGINE

Our model-based recognition engine uses standard non-articulated models of the objects to recognize the same objects in non-standard, articulated and occluded configurations. Using a technique like geometric hashing [Lamden,88], the relative positions of the scattering centers, in the range and cross-range directions, are indices to a look-up table of labels that give the associated target type and pose. The number of scattering centers used is a design parameter that is optimized based on experimental results. The recognition process

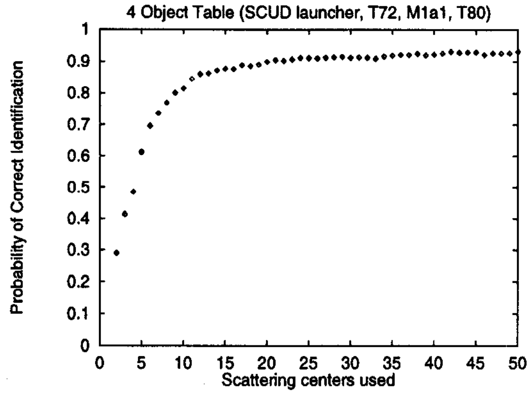


Figure 3: Effect of Number of Scattering Centers on Articulated Object Recognition.

is an efficient search for positive evidence, using relative locations of scattering centers to access the look-up table and generate votes for the appropriate object (and azimuth). The process is repeated with different scattering centers as reference points, providing multiple 'looks' at the model database to handle spurious scatterers that arise due to articulation, occlusion or noise.

4.0 RECOGNITION RESULTS

A four object recognition table for the SCUD missile launcher, T72, M1a1 and T80 is constructed from 1440 non-articulated six inch resolution target chips and tested in 2520 trials with articulated versions of these objects (tanks with turrets at 60 and 90 degrees, missile erect). Figure 3 shows the overall recognition performance is above 90 percent probability of correct identification (PCI) using the 20 to 50 strongest scattering centers. When positional noise (with zero mean) was added to the scattering center locations, the PCI (for 20 scattering centers) ranged from 90 percent at a 1/2 pixel sigma to 40 percent at a 3 pixel sigma. In Figure 4 the articulation invariant properties of the objects are used to characterize recognition engine performance, with excellent performance when the invariance with articulation is above 40 percent. Similar results are obtained in Figure 5 for object occlusion in the presence of noise, with percent unoccluded as the invariant measure, and excellent results are achieved above 40 percent unoccluded. In Figure 6 the number of votes for the true object is predicted by the empirical relation:

$$v_t = n(n-1)/2 + aM^b(1 - n/M), \tag{1}$$

where M is the number of scattering centers used, n is the number of valid scatterers and the coefficient values are $a = 4.9X10^{-3}$ and $b = 2.85$. To handle 'unknown' objects, we introduce a criteria for the quality of the recognition result that the ratio of votes for the potential winning object to the votes for the second place different object is greater than some minimum value. By varying this decision rule parameter (see Figure 7) we obtain a form of Receiver Operating Characteristic (ROC) curve with probability of correct identification vs. probability of false alarm. Figure 8 shows how target occlusion affects the recognition engine ROC curves. Other experiments were conducted with a known tank beside an unknown vehicle in the same 'target' chip. Recognition results (with 40 scattering centers and a 1.1 vote ratio) were an overall PCI of 97.8% with most of the recognition failures occurring when the unknown vehicle was in front and near 'broadside', so that less than 30% of the strongest scattering centers came from the known tank. Finally, performance is characterized for articulated occluded objects. Figure 9 shows that for the same number of scatterers used or unoccluded, the PCI of the articulated tests is greater than the PCI for the occluded articulated tests. The worse results for the occluded conditions (with the same number of valid scatterers) is due to the natural clustering of valid points in a small neighborhood for the occluded cases, which illustrates the importance of the relatively rare long distances for recognition.

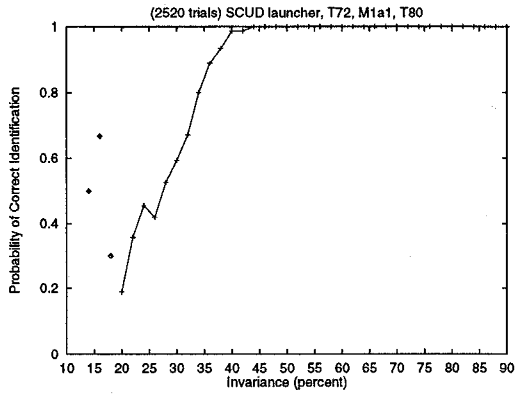
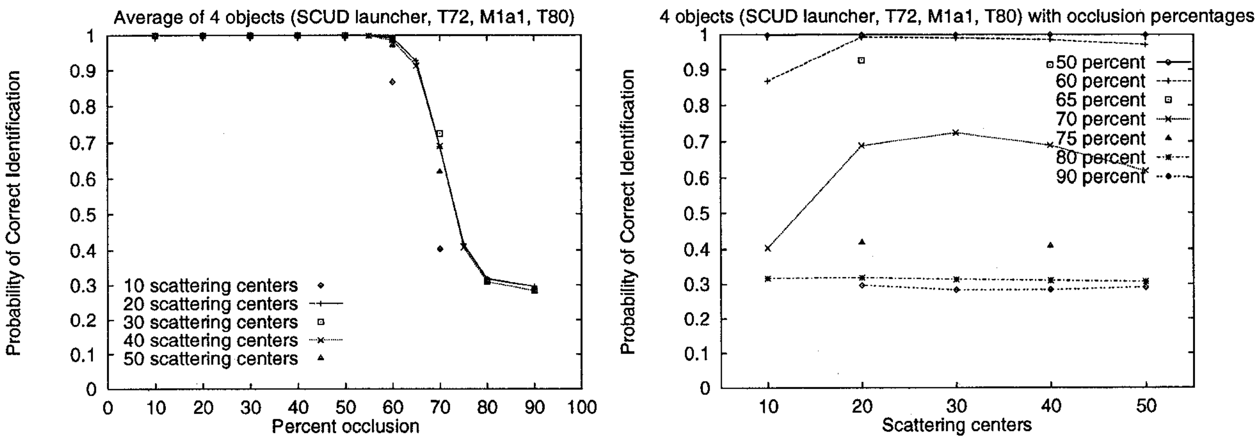


Figure 4: Recognition Rate and Articulation Invariance (50 scatterers, average of 4 objects).



(a) Effect of occlusion. (b) Effect of number of scatterers.

Figure 5: Effect of Occlusion and Number of Scatterers on Recognition Rate.

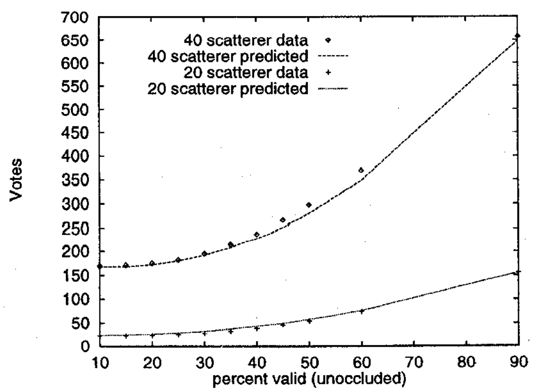
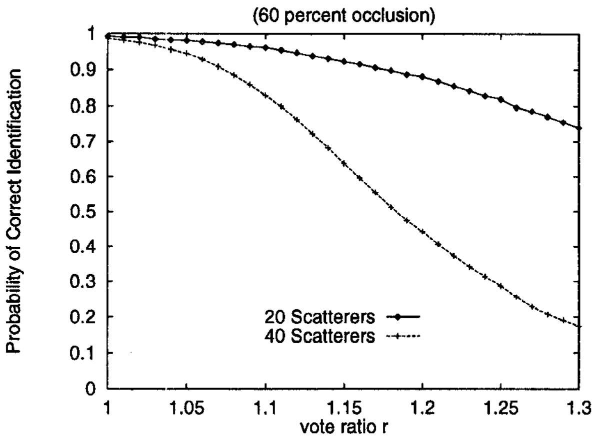
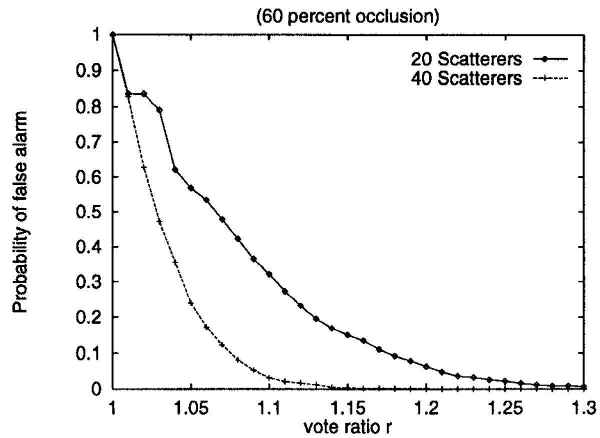


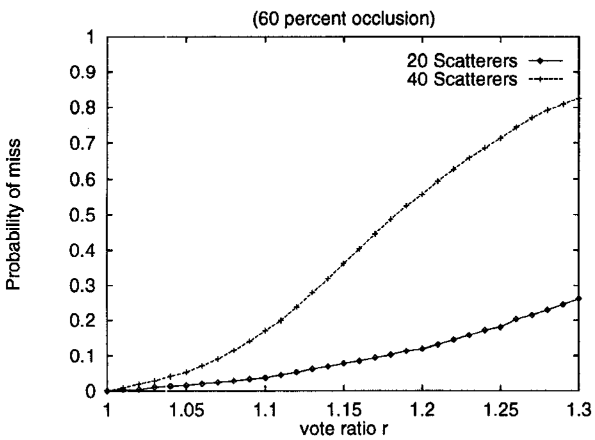
Figure 6: Occluded Performance Prediction.



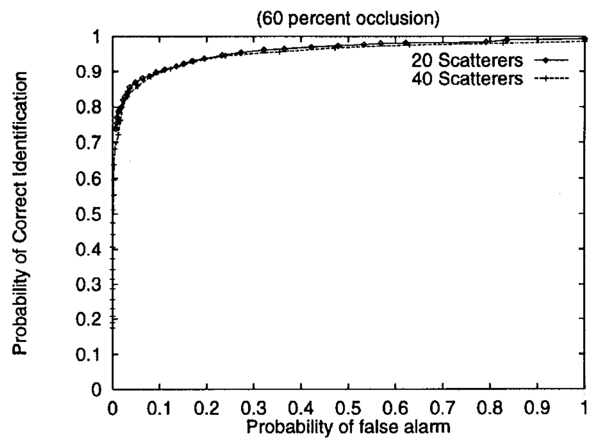
(a) Probability of correct identification.



(b) Probability of false alarm.



(c) Probability of miss.



(d) Receiver operating characteristic.

Figure 7: Receiver Operating Characteristic (60% occlusion).

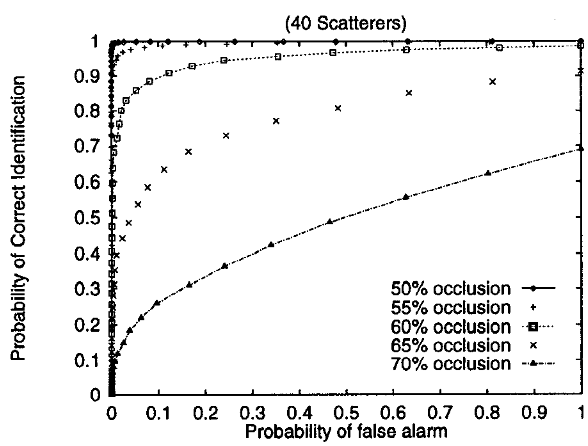


Figure 8: Effect of Occlusion on Recognition ROC curve (40 scatterers).

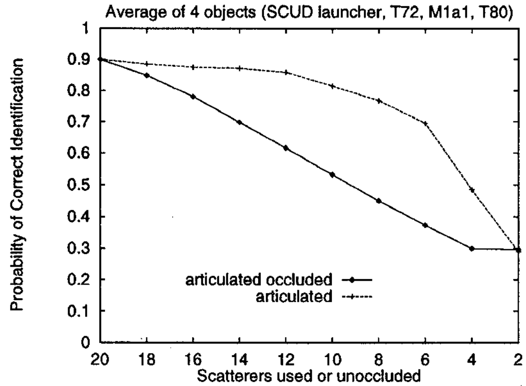


Figure 9: Articulated Object and Articulated Occluded Object Performance Results.

5.0 CONCLUSIONS

The paper outlines a new SAR specific approach, that is the first model-based automatic target recognition engine to successfully recognize articulated, occluded and articulated occluded objects in SAR images. The large azimuthal variation in six inch resolution SAR imagery is successfully captured by using 360 azimuth models for a given depression angle. Useful articulation invariant features are found in SAR images of vehicles. The feasibility of a new concept for a SAR recognition engine to identify articulated and occluded objects is demonstrated. The performance of the recognition engine can be predicted by the percent articulation invariance (or percent unoccluded) when comparing the scattering center locations of the articulated (or occluded) test images with the non-articulated model scattering center locations. The power of the technique comes from the combination of a SAR specific approach for recognition, accounting for azimuthal variance, use of articulation invariants and the resolution of the sensor.

6.0 ACKNOWLEDGEMENT

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7.0 REFERENCES

K. Ikeuchi, T. Shakunga, M. Wheeler, and T. Yamazaki, "Invariant histograms and deformable template matching for SAR target recognition." In *Proceedings IEEE Conf. on Computer Vision and Pattern Recognition*, San Francisco, Ca, pp. 100-105, June 1996.

Y. Lamden and H. Wolfson, "Geometric hashing: A general and efficient model-based recognition scheme." In *Proceedings International Conference on Computer Vision*, pp. 238-249, December 1988.

L. Novak, S. Halversen, G. Owirka, and M. Hiett, "Effects of polarization and resolution on SAR ATR." In *IEEE Trans. on Aerospace and Electronic Systems*, Vol. 33, No. 1, pp. 102-115, January 1997.

L. Novak, G. Owirka, and C. Netishen, "Radar target identification using spatial matched filters." In *Pattern Recognition*, Vol. 27, No. 4, pp. 607-617, 1994.

J. Verly, R. Delanoy, and C. Lazott, "Principles and evaluation of an automatic target recognition system for synthetic aperture radar imagery based on the use of functional templates," In *SPIE Proceedings: Automatic Target Recognition III*, Orlando, FL, Vol. 1960, pp. 57-71, April 1993.