Benefits of High Resolution SAR for ATR of Targets in Proximity

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Abstract--In this work we present a new extraction and matching algorithms that enable to perform automatic target recognition (ATR) in high-resolution synthetic aperture radar (SAR) data and targets in proximity. Our motivation was to show benefits of high-resolution SAR for ATR and extend the current capabilities of ATR algorithms for targets in extended operating conditions (EOCs), for example, targets in proximity. We develop a new extraction algorithm for target signatures represented by a point pattern. Each point pattern is extracted using a resolution independent SAR peak model. Test and prototype target signatures are compared with a new matching algorithm. The matching algorithm is capable of identifying multiple signatures in a test point pattern. An experimental evaluation of ATR performance for targets in proximity at multiple data resolution is conducted. The contribution of this work is in (a) developing a peak extraction algorithm that uses a resolution independent SAR peak model, (b) designing a new matching algorithm that can identify multiple signatures in a single test pattern, (c) evaluating ATR performance for targets in proximity at multiple data resolutions.

I. INTRODUCTION

The goal of automated target recognition (ATR) is to identify targets from measured synthetic aperture radar (SAR) imagery [1, 2]. The most common ATR system consists of three modules. They are (1) focus of attention that filters out all but regions of interest (ROI), (2) indexer that labels target candidates and (3) predict-extract-match-search (PEMS) subsystem that verifies target identifications by matching predicted signatures in a database with measured signatures. In this work, our primary interest is in the PEMS subsystem, and particularly in its extract and match components.

In the previous work [1, 4], researches have evaluated PEMS performance using a probability of correct identification (PCI) measure for targets in extended operating conditions (EOC). Robustness to EOC's is understood as the ability of PEMS subsystem to identify correctly a target that has variations not included in the database of predicted signatures. For instance, a variation in position, configuration, articulation, ground conditions or due to obscuration, targets in proximity and revetments. Most of the evaluation work has been conducted with multiple targets in open with possible articulation and configuration variations. There was no PEMS performance evaluation of targets in proximity to our knowledge. The most common SAR data resolution used in the previous evaluations was 12".

This work was motivated by the fact that the ATR systems in general have problems with targets in proximity. In addition, the problems arise when a single signature is corrupted by the presence of another target in proximity [2]. Furthermore, there was no quantitative evaluation of PEMS subsystem as a function of SAR data resolution. Performance studies with respect to data resolution are critical for new SAR sensor development. The objective of this work is to design new extraction and matching algorithms that can cope with (a) unknown targets in proximity and (b) multiple SAR data resolutions. The secondary objective is in evaluating PEMS subsystem performance in EOC's with the new algorithms and at multiple SAR data resolutions.

II. APPROACH

We approached the problem of multiple data resolution with a new feature extraction algorithm. In order to extract features at multiple SAR resolutions, a new peak model is proposed based on our theoretical analysis of canonical geometry (rectangular and circular plates). The reason behind extracting peaks particularly lies in the electro-magnetic theory of scattering centers [11]. In the past, a target signature has been mostly modeled with round peaks [4, 8]. The peaks in the previous ATR work have been modeled by either intensity maxima [4, 5] or Gaussian distribution [8] over detected target pixels at 6" and 12" resolutions. However, we have observed that the round peak model does not hold in high resolution SAR data and the Sinc (sin(x)/x) behavior along range axis is much more salient in high resolution SAR data than in low resolution SAR data, e.g., 12" data.

According to our theoretical analysis, it is more appropriate to model peaks at high resolutions with Gaussian distribution along cross-range axis and Sinc (sin(x)/x) distribution along range axis [15]. We refer to this model as a hybrid Gaussian-sinc peak model. This model reduces to a Gaussian (or round) peak model in lower resolution SAR data. Our assumptions for the peak model are that at very high SAR spatial resolution (a) target surfaces can be well approximated by a set of planar patches and (b) target parts that are not easily configurable, and therefore lead to stable features, consist of large surface patches similar to a canonical geometry dealt with in the standard electro-magnetic textbooks [11]. With the new peak model, we can estimate and extract peak parameters at any resolution and therefore address the problem of PEMS subsystem performance at multiple resolutions. A more complex target signature model has been proposed by the researches at OSU [10], such as, a parametric attributed scattering center model. Although the model is more accurate than our peak model, we have not used it because the target features would have had higher dimensionality than a point and thus matching of target signatures would become very complex. In future we would like to improve the target signature model and the matching algorithm such that a set of geometrical primitives (e.g., points, lines and regions) would be part of the signature model.

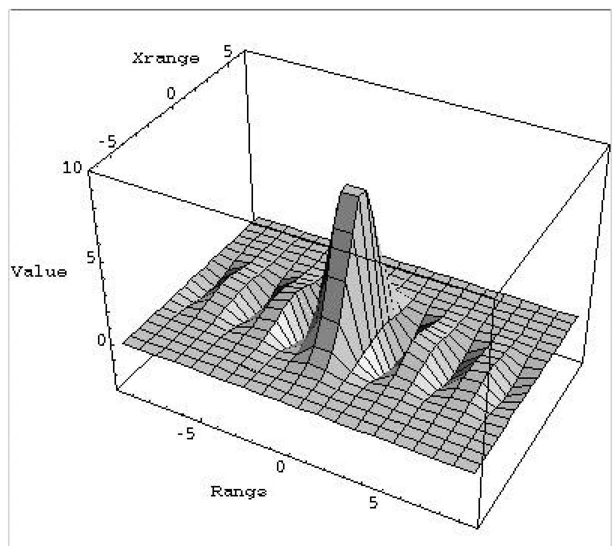
We also approached the problem of targets in proximity with a new matching algorithm. The novelty of the presented matching algorithm lies in using shape information derived from a discrete set of target signature points. In contrast with other methods [3, 4] this method converts the points into shape information denoted as s-shape and uses the s-shape representation for computationally efficient and reliable matching. Furthermore, the s-shape based matching approach uses a connectivity analysis for separating multiple unknown target signatures in a test point pattern and thus identifies successfully multiple targets in proximity.

III. OVERVIEW OF FEATURE EXTRACTION AND MATCHING ALGORITHMS

In the previous work on feature extraction, centroid locations of Gaussian (or round) peaks are found by (a) analyzing peak model [8], (b) nonlinear filtering [8], and (c) applying Delaunay triangulation [9]. In order to extract centroid locations of the Gaussian-sinc peaks, we use a hybrid filter created from a Gaussian filter along cross-range axis and a sombrero filter [13] along range axis. The mathematical description of the hybrid filter is in the equation below.

$$f(r,x) = \frac{A}{\sqrt{2ps^2}} e^{\frac{-(x-\overline{x})^2}{2s^2}} \frac{\sin(w(r-\overline{r}))}{w(r-\overline{r})} \qquad (1)$$

While the values of s (Gaussian parameter) and w (Sinc parameter) have to be found, the amplitude parameter A can be chosen arbitrarily. The variables r and x represent range and cross-range values with respect to a fixed spatial location denoted by ($\overline{r}$, $\overline{x}$). The hybrid filter model is shown in Fig. 1 for several combinations of parameters. The filter is applied over an image area with target to enhance all peaks. Since the filter parameters, such as, the width of the Gaussian s and sinc lobes w, depend on (a) data resolution and (b) the size of a target component; selecting the maximum filter response over a range of filter values approximates them. The initial filter values are estimated from a histogram of sizes of target components since the data resolution and the target CAD model are available beforehand. The filtered image is then binarized by a threshold value, which is equal to the mean plus three times standard deviation of the distribution. Peak locations are extracted from the connected "high intensity" image blobs as the blob centroids.



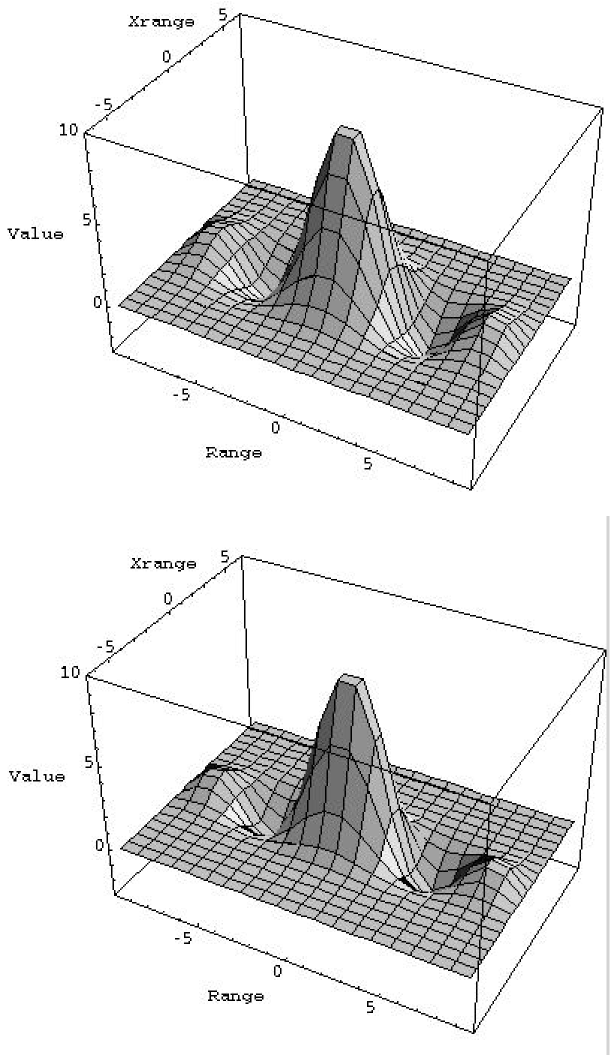


Fig. 1. Resolution independent model of peak features in SAR data. The model represents peak variations in amplitude, size of the main lobe (wide peak - middle, narrow peak - bottom) and spacing of the side lobes from the main lobe (small spacing – top, large spacing – middle and bottom).

The matching algorithm developed in this paper is based on the s-shape representation [6, 7] of a set of peak locations called point pattern. An example of a point pattern is shown in Fig. 2. The s-shape representation is defined as a set of shape parameters derived from a point pattern that was overlaid with a rectangular grid and converted into compact regions containing connected grid cells occupied with at least one point (see Fig. 1 and Fig. 3). The set of shape parameters is a succinct representation of a target signature that provides means for computationally efficient and reliable matching. Furthermore, the s-shape based matching approach uses a connectivity analysis for separating multiple unknown target signatures in a test signature and thus can identify successfully multiple targets in proximity.

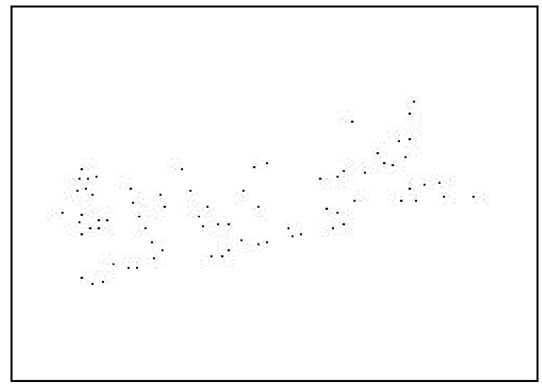


Fig. 2 Point pattern of Btr70 prototype target signature generated at depression angle equal to 30 degrees and azimuth angle equal to 60 degrees.

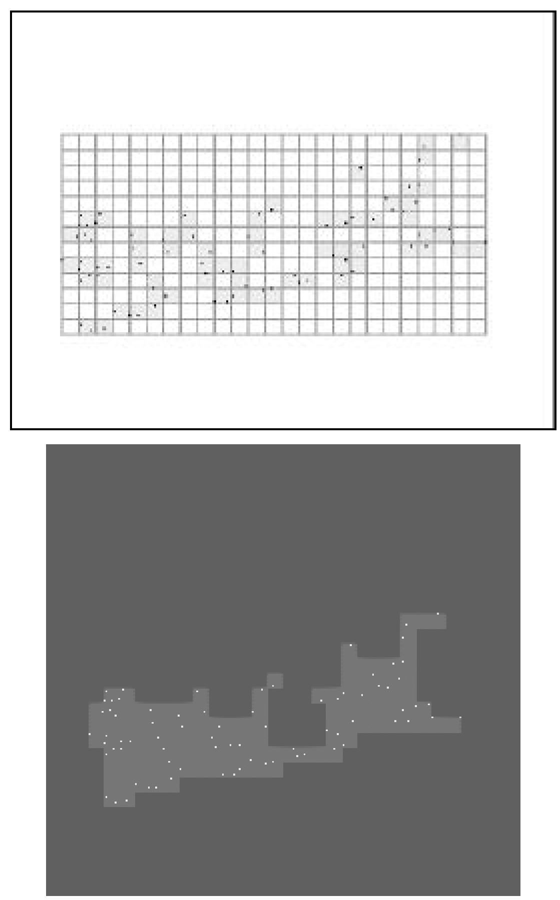


Fig. 3. The derived binary image (top) from point pattern shown in Fig. 2 and the smoothed version (bottom) of the binary image. These images represent the s-shape matrix and its smoothed version scaled by the grid side length.

The following steps can summarize our matching algorithm. First, the grid size is estimated based on the density of a point pattern distribution [6, 7]. Second, regions are detected by selecting connected grid cells that are occupied by at least one point. Third, these regions are filtered with a morphological closing in order to enhance stable region geometry. Fourth, the best position for matching a prototype target signature to an unknown signature is found by minimizing border and non-border mismatch measures for the candidate prototype. The prototype with minimum mismatch measure at its best-fit location is recorded as the best match for the test target. However, if the outcome provides multiple results, i.e., optimal mismatches are attained for multiple prototypes (at the same or different locations of the test target) then we use an additional measure based on shape parameters of the prototype and its matched subregions in the test target (such as grid size, number of points, size of bounding rectangles, center of mass, and shape number). Fifth, the subset of the test pattern that gave rise to connected regions in the second step is removed from the test point pattern. The algorithm continues from step one until the number of remaining points is above some threshold or the best match is below a minimum score.

IV. EXPERIMENTS AND RESULTS

We used two CAD models of Btr70 and Btr80 targets in our experiments. The signatures of Btr70 and Btr80 are similar to each other under optical or SAR sensors and therefore they create a challenge for any ATR system. All SAR target signatures were generate by running Xpatch simulations [14]. The Xpatch simulations used decimated 3D CAD models with several viewing and articulation variations shown in Fig. 4 and Fig. 5.

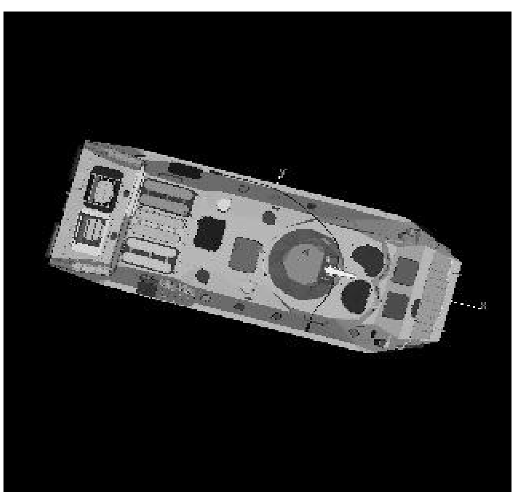


Fig. 4. An example of a decimated 3D CAD target model in open with variations in aspect angle.

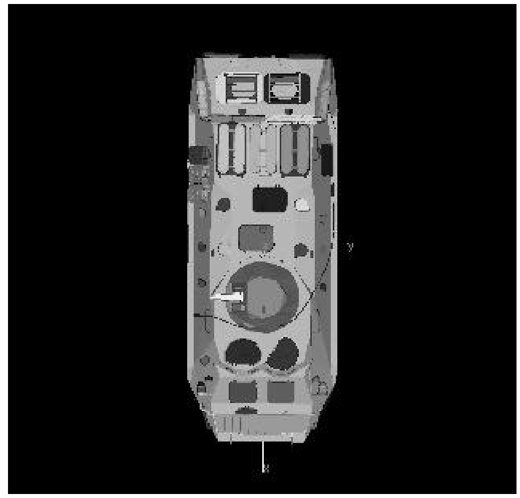
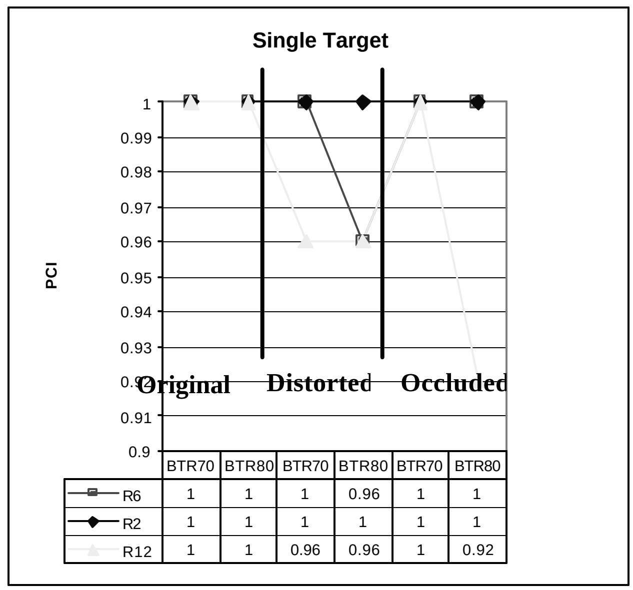


Fig. 5. An example of a decimated 3D CAD target model in open with variations in turret articulation.



	BTR70	BTR80	BTR70	BTR80	BTR70	BTR80
R6	1	1	1	0.96	1	1
R2	1	1	1	1	1	1
R12	1	1	0.96	0.96	1	0.92

Fig. 6. Results of the experiments with a single target. The chart shows probabilities of correct identification (PCI) at multiple resolutions (R) while performing ATR under various extended operating conditions

In our first set of experiments we used several levels of signature occlusion and distortion. For example, in Fig. 6, 50% randomly selected features were missing or displaced in a local circular neighborhood whose radius is defined as a function of the grid-size. The second set of experiments involved target proximity related experiments (two targets were placed side-by-side at 4, 5 and 6 m or behind each other at 8, 9 and 10 m). The proximity scenarios are shown in Fig. 7 and Fig. 8. The mutual distance was measured from a CAD center of one target to a CAD center of the other target. All these configurations were modeled for 24 aspect angles from 0 to 360 degrees, with 15-degree increments and at 30-degree depression angle and at 2”, 6” and 12” data resolutions. The prototype database always contained two non-articulated targets, Btr70 and Btr80. The results of a probability of correct identification (PCI) are shown in Fig. 6 (single target) and Fig. 9 (targets in proximity). Both figures demonstrate importance of high resolution SAR data for accurate ATR and the results provide quantitative measures of accuracy for each target model and a proximity configuration.

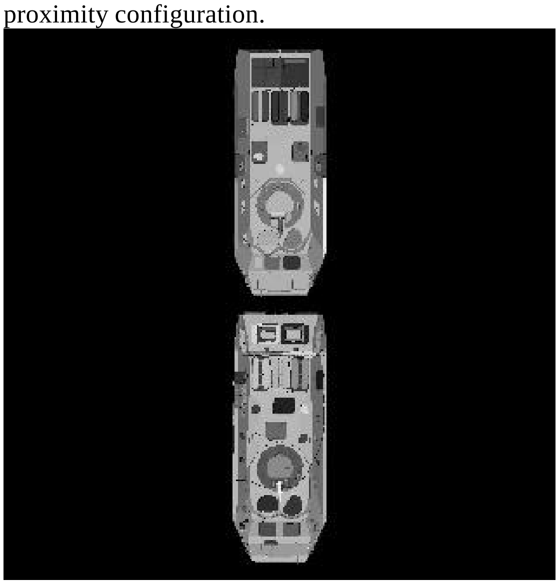


Fig. 7. Scenario with two targets modeled behind (B) each other.

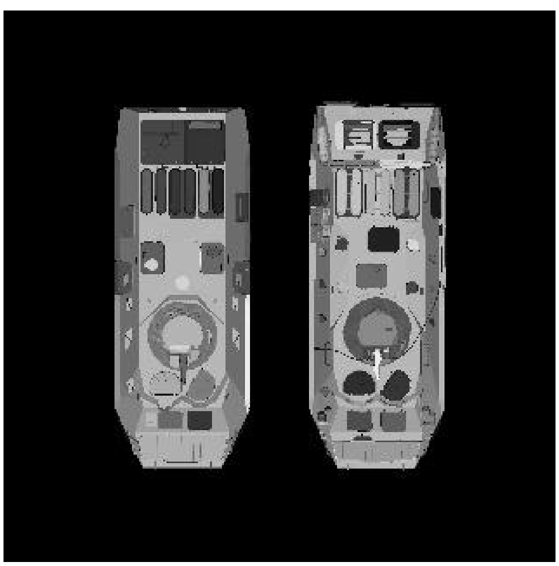
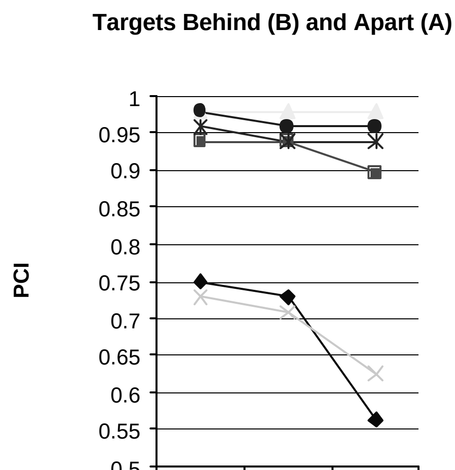


Fig. 8. Scenario with two targets modeled apart (A) from each other.



	B10/A6	B9/A5	B8/A4
B12	0.75	0.729	0.563
B6	0.938	0.938	0.896
B2	0.979	0.979	0.979
A12	0.729	0.708	0.625
A6	0.958	0.938	0.938
A2	0.979	0.958	0.958

PCI

Fig. 9. Results of the experiments with targets in proximity. The chart shows the probability of correct identification (PCI) from SAR signatures as a function of mutual distance (behind by 10, 9 and 8 m; and apart by 6, 5 and 4 m) and data resolution (2”, 6” and 12”).

V. SUMMARY

We have presented a new extraction and matching algorithms that enabled automatic target recognition (ATR) in high-resolution synthetic aperture radar (SAR) data with targets in proximity. Our focus was on benefits of high-resolution SAR for ATR in addition to the algorithmic development that extended the current capabilities of ATR algorithms for targets in close proximity. We have developed a new extraction algorithm for target signatures represented by a point pattern with a resolution independent SAR peak model. The obtained target signatures were compared using a new matching algorithm that is capable of identifying multiple signatures in a test point pattern. We concluded based on the experimental evaluation of ATR performance for targets in proximity at multiple data resolution that the SAR data resolution is critical for a satisfactory ATR performance. This research has shown a significant ATR performance improvement for targets in proximity when the SAR data resolution increased from 12” to 6”. The ATR performance improvement from 6” to 2” SAR data resolution was less significant than the improvement recorded from 12" to 6" SAR data resolution. However, we believe that the robustness of ATR systems in a presence of multiple variables included in EOCs might be more sensitive to the choice of 2" versus 6" SAR data resolution. This issue remains to be explored in our future investigations.

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