Segmentation of ISAR Images of Targets Moving in Formation

Paper Review

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Outline

1. Introduction

2. Proposed method
   - Existing range alignment methods
   - Contributions

3. Experiments

Paper

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Segmentation of ISAR Images of Targets Moving in Formation

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Motivation

- Inverse Synthetic Aperture Radar (ISAR) images.
- Segment multiple targets flying closely spaced in a formation.
  - Improve range-Doppler technique used for single targets.
  - Propose a new range alignment method which aligns range profiles using a polynomial that best represents the trajectory.
  - PSO is used to estimate the parameter of the polynomial.

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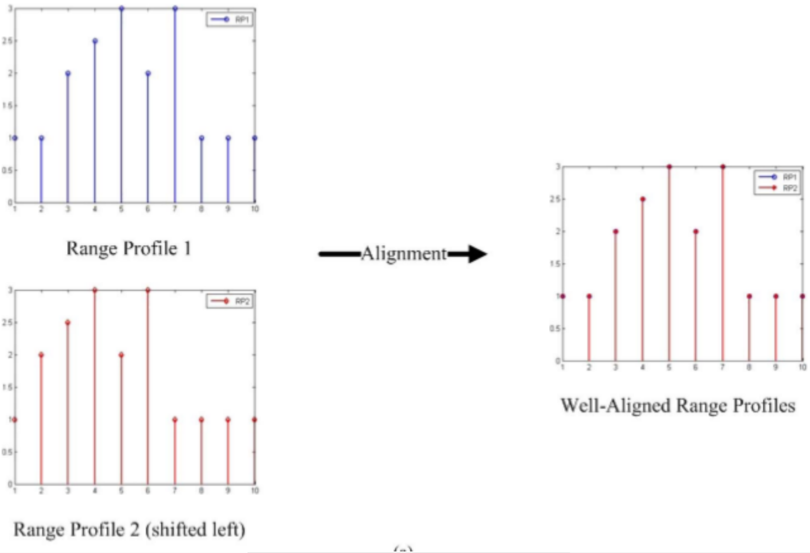
Single target example



Entropy cost function

$$H_{G_m,G_{m+1}} = -\sum_{0}^{N_p-1} \overline{G}(k,n)\ln \overline{G}(\sigma,n)$$

where

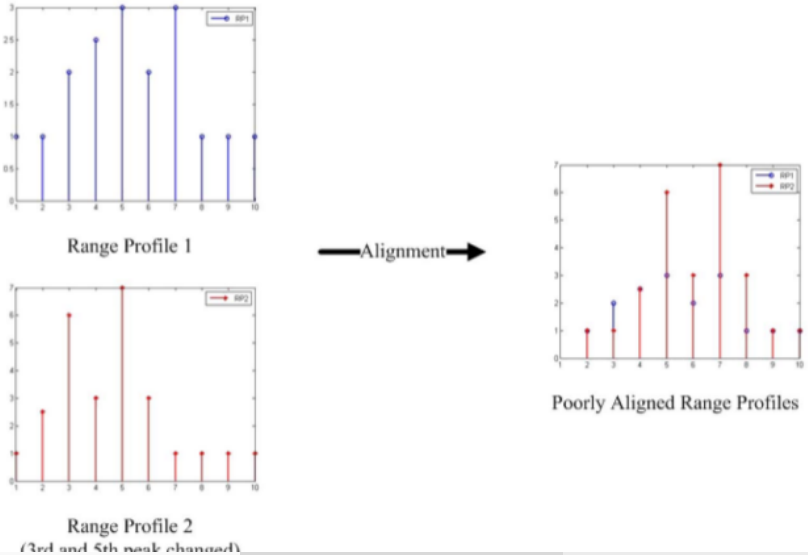
$$\overline{G}(\tau,n) = \frac{|G_m(n)| + |G_{m+1}(n-\sigma)|}{\sum_{0}^{N-1} (|G_m(n)| + |G_{m+1}(n-\sigma)|)}. \qquad (4)$$

$G_m(n)$ and $G_{m+1}(n)$ are the range profiles m and $(m+1)$ of range bin n, respectively, N_p is the total number of range bins, and σ is an integer shift that is used to align the profiles.

Problems

- Alignment using entropy is effective in imaging a single target because neighboring range profiles are higly correlated.
- Targets flying in formation are located in a single radar beam.
    - Scattering centers from different targets can occur in the same range bin.
    - Constructive and destructive interferences -> uncorrelation.

Multiple target example



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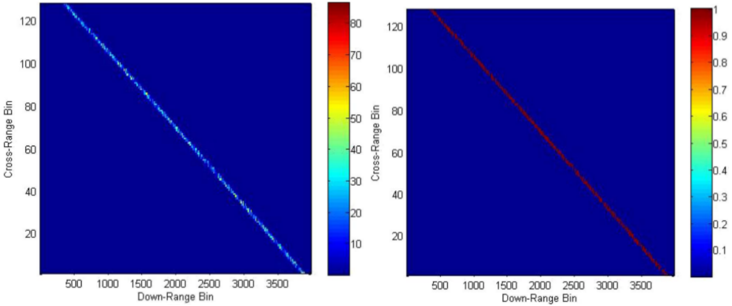
Requirements

1. All pixels, not just those having high values, must have the same effect on the range alignment.
2. The cost function must be appropiate for the multiple target case.

Requirement 1

- Construct a new binary image instead of using the range profile history itself.
- Select η range bins having the highest amplitudes in each range profile and change their value to one.
- The amplitudes in the other range bins are all changed to zero.
- The value of η is calculated as the number of range bins in each range profile having amplitudes higher than 10% of the maximum value.

Requirement 1 example

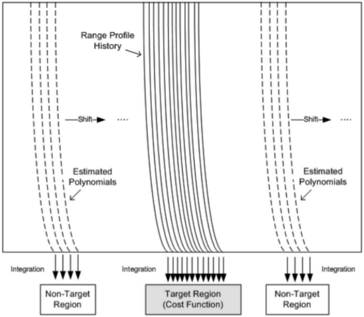


Requirement 2

To achieve 2), we model the shifts of the range profiles $(R(t))$ as a polynomial

$$R(t)=1+a_1t+a_2t^2+a_3t^3\ldots, \qquad t=0,1,\ldots,M-1 \quad (5)$$

where M is the number of range profiles and a_i are the fitted parameters. We round $R(t)$ to the nearest integer. We then define the cost function as the sum of the values of the pixels that occur at the polynomial location on the new image. If the sum is large, the polynomial represents the trajectory well, and the alignment can be accomplished easily using the fitted parameters. However, because range bins belonging to the targets in a range profile history comprise a region, not a single line, serious errors can occur if one maximum number of the integrated value is used for the alignment. Instead, shifting $R(t)$ sequentially from the first to the last range bins and summing the pixel values on the polynomial for each shift (Fig. 2), we utilize as the cost function the sum of the η highest sums that best represents the range profile history. Therefore, the cost function yields the maximum value when the polynomial fits the trajectory well. To reduce the computation time, we can reduce the search space by using only the shifts that yield a cost function > 0 by positioning the trajectory in the target region (Fig. 2).



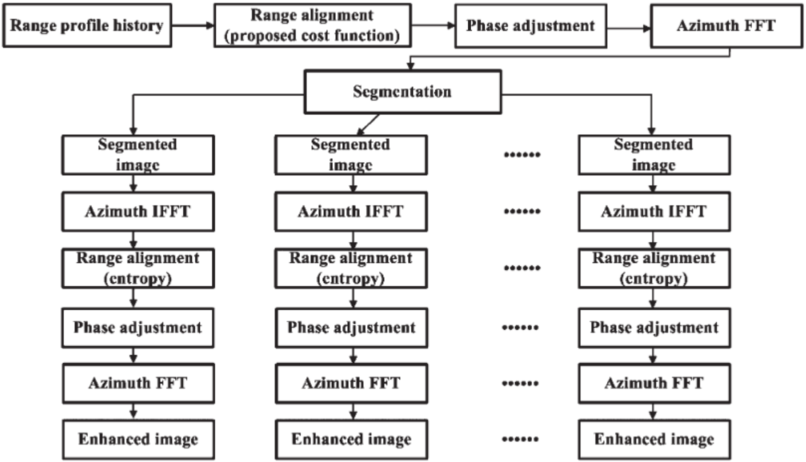
PSO

We use PSO to find the coefficients in (5) because it is easy to implement and has proven to be efficient for several engineering problems [13]. The system is initialized with a population of random solutions (particles) that minimizes a cost function; then, the algorithm searches for local and global particle optima by changing the velocity vector of each particle. The particle dynamics which updates each particle is as follows:

$$\vec{v}_i(t) = \phi \vec{v}_i(t-1) + \rho_1 \left(\vec{x}_{\text{pbest}} - \vec{x}_i(t)\right) + \rho_2 \left(\vec{x}_{\text{gbest}} - \vec{x}_i(t)\right) \quad (6)$$

where t is the generation number, ϕ is the inertial weight, $\rho_1 = r_1 c_1$, $\rho_2 = r_2 c_2$, $c_1, c_2 > 1$ and $c_1 + c_2 < 4$, and r_i is drawn from a random uniform distribution from zero to one. Then, the velocity vector $\vec{v}_i(t)$ in generation t is added to the position vector $\vec{x}_i(t)$ to move this particle.

Proposed segmentation procedure



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Simulated targets

In this simulation, we assume three targets separated along the x-axis on the same xy plane (i.e., altitude). Two types of targets are used (Fig. 6); these were modeled using the 3-D CAD data of Russian Su-35 and American F-14 fighters (www.3dcadbrowser.com). The Su-35s are represented as 60 isotropic point scattering centers and the F-14s as 50 such centers. Simulation data were obtained by assuming that two Su-35s and one F-14 were flying in a formation in the $[-1 \ \ -1 \ \ 0]$ direction with velocity $v = 300$ m/s and acceleration $a = 10$ m/s^2 starting from the initial positions $[x_1 \ \ y_1 \ \ z_1] = [0.310 \ \ 50.0 \ \ 3.0]$ km (first Su-35), $[x_2 \ \ y_2 \ \ z_2] = [0.335 \ \ 50.0 \ \ 3.0]$ km (second Su-35), $[x_3 \ \ y_3 \ \ z_3] = [0.285 \ \ 50.0 \ \ 3.0]$ km (F-14). Reflected signals were collected using (1) and (3).

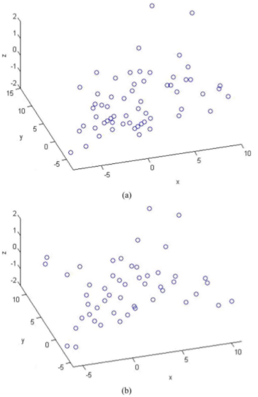
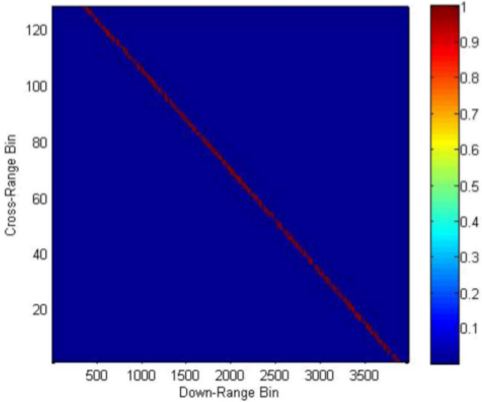


Fig. 6. Targets composed of scattering centers. (a) Three-dimensional representation of Su-35 consisting 60 point scattering centers. (b) Three-dimensional representation of F-14 consisting 50 point scattering centers.

Range profila cost function



ISAR results

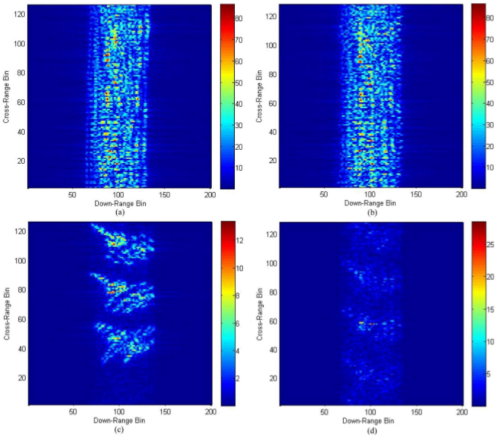


Fig. 8. Comparison of the alignment results (segmented alignment) and ISAR images. (a) Segmented alignment. (b) Range alignment using the entropy cost function. (c) ISAR image computed using (a). (d) ISAR image computed using (b).