ISAR IMAGING OF MULTIPLE TARGETS USING EDGE DETECTION AND HOUGH TRANSFORM

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Abstract—This paper describes a fast method to derive ISAR images of multiple targets with different motion parameters. We use image processing techniques, edge detection and the Hough transform to find the slope of the range profile history of each target and to separate each range profile history. Simulation results of two closely spaced targets with different motion parameters confirm the effectiveness of this method.

1. INTRODUCTION

Inverse Synthetic Aperture Radar (ISAR) imaging [1] is a technique to generate a two-dimensional high resolution image of a target. It is widely used for automatic target recognition along with the 1-D range profile [2] and natural frequency [3]. Currently, the main limitation to ISAR imaging is motion compensation because imaging targets may have complicated motion components, which can degrade the resolution of the image. Algorithms based on Fourier transform and time frequency analysis can compensate for the motion component of a single target [4]. However, when multiple targets occur in a single radar beam, it is difficult to image each target separately. Some algorithms have been proposed to solve this problem, but none is fully satisfactory. One proposed method utilizes maximum likelihood estimation and assumes that the number of the targets is known, which
is impossible in real cases [5]. Another method is based on time-Doppler frequency analysis [6], but this method has limited application because it requires the range migrations of all targets be equal. Other conventional methods also have limitations. In this paper, we propose a fast ISAR imaging method to image multiple targets. We used image processing techniques, edge detection and the Hough transform [7, 8] to separate the range profile history of each target. Then the separated range profile histories were motion-compensated by a conventional Fourier transform. Simulation results show that two closely spaced targets can be separated successfully and motion-compensated even when accelerating.

2. RADAR SIGNAL MODEL AND PROPOSED MOTION COMPENSATION METHOD

2.1. Radar Signal Model for Imaging
For the radar signal, we assume a monostatic chirp waveform because it is more widely used than bistatic method [9, 10]. The transmitted chirp signal can be expressed as follows:

\[ r(t) = A_0 e^{j2\pi(f_0 t + 0.5 B t^2)} \text{rect}\left(\frac{t}{\tau}\right) \]  

(1)

where \( r(t) \) is the transmitted signal, \( f_0 \) is the start frequency, \( B \) is the bandwidth, \( A_0 \) is the amplitude and \( \tau \) is the pulse duration. In the case of multiple targets, the received signal \( g(t) \) is:

\[ g(t) = \sum_{k=1}^{K} \sum_{n=1}^{N} A_{k,n} e^{j2\pi[f_0(t-d_{k,n})+0.5 B (t-d_{k,n})^2]} \text{rect}\left(\frac{t-d_{k,n}}{\tau}\right) \]  

(2)

where \( d_{k,n} \) is the time delay between the radar and the nth scattering center of the kth target, \( N \) is the number of scattering centers and \( K \) is the number of the targets. This returned signal is then matched-filtered to obtain range profiles at a certain aspect angle [11] and for each range bin, inverse Fourier transform is used to derive the ISAR image. To collect more accurate radar crosssection (RCS) data, various numerical methods can be used [12].

2.2. The Proposed Motion Compensation Method
Fig. 1 shows the proposed method to compensate the motion of the multiple targets. The premise of this method is that the range profile history is composed of several lines of a certain slope. This
is a reasonable assumption if the observation time is short compared with the velocity of a target. Even for long observation time and high acceleration, it is reasonable because range profiles can be divided into several segments and this method can be applied to each segment.

In this method, the absolute values of the range profile histories of the multiple targets are utilized and edges of these 2-D data are extracted. The reason for edge detection is to sharpen the values derived by the Hough transform of edge information. For edge detection, one of the Sobel, Roberts, Canny, and Prewitt methods is utilized [7]. Then by using the Hough transform of edge information, the slope of the range profile history of each target is estimated. Permuting all combinations of data points to calculate the slope of the lines can require enormous computation time, but the Hough transform solves this problem by directly finding the angle and intercept of a line. In the case of a line represented by (3), the Hough transform represents
this line in the \((\theta, \rho)\) domain.

\[ x \cos \theta + y \sin \theta = \rho \]  

(3)

Fig. 2 shows 4 lines of different slopes and intercepts and their Hough transform values. 4 peaks appear in each corresponding \((\theta, \rho)\) position. For this reason, values for the angle range of \(-90^\circ \sim 90^\circ\) can be used for slopes. In this method, the difference between the average of the highest 5 values and that of the lowest 5 at each angle is utilized. The reason for this is that Hough transform values can have high values for some unrelated angles in case of many edge components. In separating a range profile history using a slope, to remove any possible contribution from high-valued scattering centers, we construct a matrix whose values are identically one when the corresponding values in the range profile history are higher than a threshold (15 \sim 20\% of the maximum). Then we shift a line of the found slope from the right lower corner to the left lower and integrate values on the line of the matrix. The points that lie on the line of a shift for which integrated values exceed a threshold are the location of the data that belong to the range profile history.

After range profiles are separated, range bins are aligned. When the number of pulses is small, range bins can be aligned by minimizing 1-D entropy function between two range profiles given as follows [12]:

\[ H_{G_m,G_{m+1}}(\tau) = -\sum_{n=0}^{N-1} G(\tau,n) \ln G(\tau,n) \]  

(4)

where,

\[ G(\tau,n) = \frac{|G_m(n)| + |G_{m+1}(n-\tau)|}{\sum_{n=0}^{N-1} (|G_m(n)| + |G_{m+1}(n-\tau)|)} \]

\(G_m\): \(m\)th range profile

However, this process is time-consuming because for each range profile, 1-D entropy should be calculated for all the shifts with respect to the reference envelope to find the minimum entropy. Therefore, to reduce computation time, we use the slope. Using the slope, the scattering centers which occur on the same line are shifted directly to the position of the first one. This process reduces calculation time. When observation time is long, range profiles are divided into several segments and for each segment, the same procedure is carried out. To align the aligned segments, 1-D entropy minimization method is used because there are only a few segments. For phase adjustment, the 2-D minimum entropy phase adjustment method is used [13].
3. SIMULATION RESULTS

Fig. 3 shows the flight scenario of two targets. Target 1 starts from (0.1, 10.1) Km, and descends at 30° with an initial velocity of 250 m·s\(^{-1}\) and an acceleration of 2 m·s\(^{-2}\). Target 2 starts at (0.1, 10.1) Km and descends at 45° with initial velocity of 300 m·s\(^{-1}\) and an acceleration of 5 m·s\(^{-2}\). Initially, the wings of the targets partially overlap. The amplitudes of scattering centers of the two targets are identical. They are observed for 1024 pulses by an X-band radar whose pulse repetition frequency is 2 kHz and down-range resolution is 0.75 m (bandwidth = 200 MHz).

Figure 3. The flight scenario of two targets.

Fig. 4 shows the range profile history of the two targets. Because of the targets' acceleration, the traces on this figure are not linear. Therefore, range profiles are divided into 4 segments of 256 profiles to calculate piecewise straight lines and the Hough transform is applied to each line. Fig. 5 shows the edge information derived by the Sobel method in the first segment, and the difference between the average of the 5 highest Hough transform values and that of the 5 lowest for \(-90° \sim 90°\). In Fig. 5(a) the Hough transform indicates that the slopes are 5.8° and 10.0° with respect to the vertical axis. Using these slopes, the range profile history of each segment was separated. Fig. 6 shows separated range profile histories of the two targets in the first segment.

After separating range profile histories, range alignment was carried out using the slope as proposed in section 2. Using a Pentium IV 3.0 GHz processor, Table 1 compares the effectiveness of this
Figure 4. The total range profile history of two targets.

Figure 5. (a) Edge-detected range profile history of first segment (b) The difference between the averages of the 5 highest values and the 5 lowest values.

Figure 6. Separated range profile histories in the first segment. (a) target 1 (b) target 2.
Figure 7. ISAR images of the two targets: (a) target 1 (b) target 2.

Figure 8. ISAR images of the two methods: (a) proposed method (b) 1-D entropy minimization.

method compared with 1-D entropy minimization for varying range profile (pulse) numbers. As can be seen from Table 1, range bin alignment using the slope is much faster than 1-D entropy minimization method because range bins are directly aligned using the slope found by Hough transform. Then Fig. 7 shows focused ISAR images of the two targets after range alignment and phase adjustment. They are successfully separated and motion-compensated. Fig. 8 compares ISAR images of target 1 derived from two range alignment methods by the slope and the 1-D entropy minimization. In this figure, there is no degradation in the image derived by the slope compared with 1-D entropy minimization. This proves the accuracy of this method.
Table 1. Time for range alignment by the proposed method and 1-D entropy minimization method.

<table>
<thead>
<tr>
<th>No. of pulses</th>
<th>Proposed method</th>
<th>1-D Entropy minimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1024</td>
<td>13.3 s</td>
<td>9 min 15.2 s</td>
</tr>
<tr>
<td>2048</td>
<td>27.2 s</td>
<td>18 min 35.2 s</td>
</tr>
<tr>
<td>3072</td>
<td>40.2 s</td>
<td>27 min 51.2 s</td>
</tr>
</tbody>
</table>

4. CONCLUSION

In this paper, we proposed a new method for fast ISAR imaging of multiple targets. It is based on basic image processing techniques, edge detection and Hough transform. Computer simulation results of two closely spaced targets verified the effectiveness of this algorithm. Using the proposed method, time to search for the slopes of the range profile histories was reduced because the Hough transform found them directly by using edge detection information. Then the range profile histories of different targets were successfully separated by these slopes.

In addition, compared with the 1-D entropy minimization method, much less time is spent on range alignment without any undesirable effects on the final image in spite of high acceleration.

REFERENCES


