ESTIMATION OF TARGET MOTION AND 3D TARGET GEOMETRY USING MULTISTATIC ISAR MOVIES

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1. INTRODUCTION

Inverse synthetic aperture radar (ISAR) is one of the radar techniques used to observe two-dimensional images of a remotely based target using radio waves[1][2]. If we keep observing the target long enough and consecutively generate multiple ISAR images, which we call ISAR movie, the target image varies considerably, since the image plane varies according to the change of the relative position and the motion of the target. We proposed an algorithm for reconstructing three dimensional target shape from an ISAR movie [3]; however, the algorithm requires a priori knowledge about the relative motion of the target, which is not so realistic. In this paper, we propose a novel method that estimates the relative motion and the three dimensional shape of the target using multistatic ISAR movie.

2. GEOMETRY AND THE METHOD

Fig.1 shows the geometry. We assume that the target is rigid and is consisted of K point scatterers, whose positions are denoted as $\overline{p}_k$ ($k=1,\cdots,K$). The target is assumed to be rotating around an axis passing through the origin O with constant angular velocity $\overline{\omega}$. The feature of the method is that we have two auxiliary receiver antennas. In Fig.1, $\overline{d}_1$ and $\overline{d}_2$ represents the baselines from antenna #0 to #1 and #2, respectively, $\hat{r}$ is a unit vector representing the radar line of sight from antenna #0 to the origin, and r_0 is the distance between antenna #0 and the origin. Here we assume r_0 is sufficiently large compared to the size of the target and baseline length. The antenna #0 transmits pulses and antenna #0, #1, #2 receive the pulses scattered by a target. Using the received signals, we observe three ISAR movies as shown in Fig. 2. The signal from a point scatterer at position $\overline{p}_k$ is appeared as a blob at range r_{kn} and Doppler frequency f_{dkn} on the n -th frame of the ISAR movie observed by the antenna #0, and the range r_{kn}, Doppler frequency f_{dkn} satisfy following relationships:

$$r_{kn} \approx \hat{r}\cdot\overline{p}_k \qquad (r_0 \gg \|\overline{p}_k\|) \ , \tag{1}$$

$$f_{dkn} = \frac{2\dot{r}_{kn}}{\lambda} \approx \frac{2}{\lambda}\hat{r}\cdot\dot{\overline{p}}_k \ , \tag{2}$$

where λ is the wave length. On the other hand, the velocity of the point scatterer satisfy the following relationship:

$$\dot{\overline{p}}_k = \frac{d}{dt}\overline{p}_k = \overline{\omega}\times\overline{p}_k \ . \tag{3}$$

The blob that corresponds to the point scatter $\overline{p}_k$ appears in each of the three ISAR movies. We denote their complex amplitudes as s_{0kn}, s_{1kn} and s_{2kn} respectively (Fig.2). Then the time derivative of the phase differences $\phi_{jkn} = \angle s_{jkn}s^*_{0kn}$ ($j=1,2$; $*$ denotes complex conjugate) satisfy the following relationship:

$$\dot{\phi}_{jkn} = \frac{d\phi_{jkn}}{dt} \approx \frac{2\pi}{\lambda}\left(\overline{\overline{I}} - \hat{r}\hat{r}^T\right)\frac{\overline{d}_1}{r_{kn}+r_0}\cdot\dot{\overline{p}}_k \ . \tag{4}$$

Based on the above formulation we can estimate $\overline{\omega}$ and $\overline{p}_k$ by the following procedure.

Step 1) Estimation of the three dimensional velocities $\dot{\bar{p}}_k$ of the scatterers

Using equations (2) and (4), we can estimate $\dot{\bar{p}}_k$. Here, $\bar{d}_1, \bar{d}_2, \lambda$ are system parameters, and we can obtain r_0 and $\hat{r}$ from the observed signal, r_{kn}, f_{dkn} are also observed from ISAR movies. $\dot{\phi}_{jkn}$ are estimated by least squares method using the observation from several frames around n-th frame.

Step 2) Estimation of the angular velocity $\bar{\omega}$ and the positions $\bar{p}_k$

Noting that $\dot{\bar{p}}_k \perp \bar{\omega}, \forall k$, we can estimate the direction of the axis of the rotation $\hat{\omega}$ by applying the principal component analysis to $\dot{\bar{p}}_k$ ($k = 1, \cdots, K$). Namely, we first obtain the covariance matrix $\bar{\bar{C}} = \sum_{k=1}^{K} \dot{\bar{p}}_k \dot{\bar{p}}_k^T$, then we use the eigenvector corresponding to the minimum eigenvalue as the estimation of $\hat{\omega}$. Then the equations (1) and (2) can be solved by least squares method with direct search over reasonable range for $\|\bar{\omega}\|$.

4. CONCLUSION

We proposed an algorithm to reconstruct 3-D target shape from ISAR movie. The algorithm is based on the least squares estimation of the relative motion of the target and the positions of point scatters that constitute the target. We conducted some numerical simulations to verify the effectiveness of the algorithm (see Fig.3).

5. REFERENCES

[1] Donald R.Wehner, "High-Resolution Radar Second Edition," Artech House,1995.

[2] Bernard D. Steinberg and Harish M. Subbaram, "Microwave Imaging Techniques," John Wiley & Sons,1991.

[3] Masafumi Iwamoto, and Tetsuo Kirimoto, "A novel algorithm for reconstructing three-dimensional target shapes using sequential radar images," *IGARSS 2001*, pp. 1607-1609, Jul. 2001.

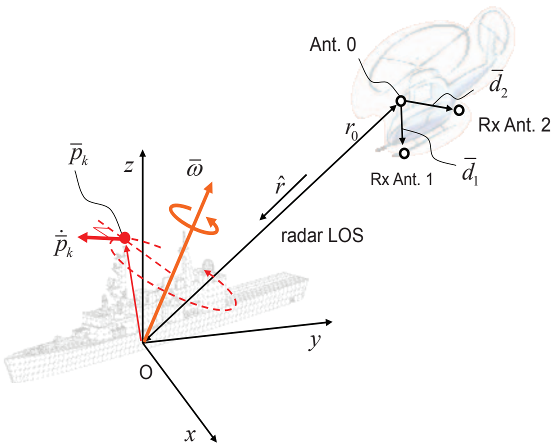

Fig.1 Geometry

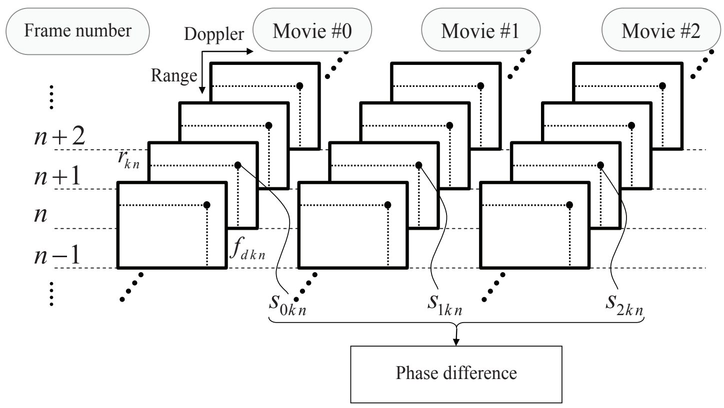

Fig.2 ISAR movie

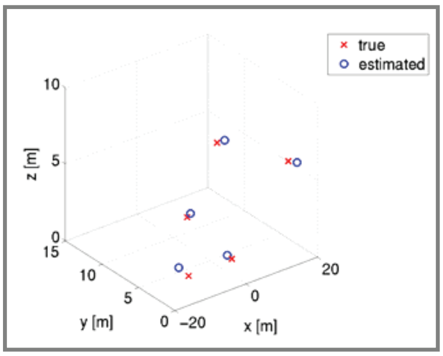

Fig.3 Numerical simulation

Fig. 3 shows the result of a numerical simulation. The target has been assumed to be consisted of 5 point scatterers, and its angular velocity is assumed to be unknown. Other conditions for the simulation are shown in the table below.

parameters	value	parameters	value
d_1, d_2	2m	The number of frames	5
fc	33GHz	The number of scatterers	5
B	100MHz	SNR	20dB
PRI	0.01sec	Target distance	5km
The number of pulses	128	Target angular velocity	0.65 deg/sec