PROCEEDINGS OF ISAP2005, SEOUL, KOREA

# EFFICIENT MOTION COMPENSATION FOR ONE-DIMENSIONAL STEPPED FREQUENCY RADAR SIGNALS

Kyung-Tae Kim and *Ho-Ryung Jung
School of Electrical Engineering and Computer Science, Yeungnam University,
214-1, Dae-dong, Gyeongsan-si, Gyeongsangbuk-do, Korea 712-749
*Department of EEE, Pohang University of Science and Technology
San 31, Hyoja-dong, Nam-gu, Pohang-si, Gyeongsangbuk-do, Korea 790-784
E-mail : juniorf@yumail.ac.kr, *azmodan@postech.ac.kr

## 1. Introduction

Stepped-frequency radar system dedicated to target imaging collects reflectivity data in a two-dimensional (2-D) time-frequency span while a target maneuvers. Target motion introduces phase distortion proportional to the change of the instantaneous range to the target. Consequently, the image of the moving target tends to be blurred. In order to obtain focused range profile, the kinematic motion parameters associated with the target must be estimated to compensate the phase of the reflectivity data [1]. Fig. 1 shows blurred 1-D radar images, i.e., range profiles of a target with the change of its velocity.

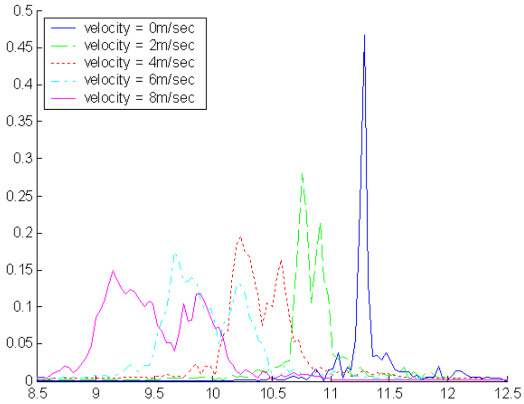

Fig. 1 Distortion of range profiles of a target with the change of its velocity

There have been many attempts to restore the inverse synthetic aperture radar (ISAR) images from 2-D stepped frequency radar signals of a maneuvering target [2]. However, it is very difficult to find any algorithm to correct the distortion occurring in the range profiles (see Fig. 1) from 1-D stepped frequency radar signals. In this paper, we propose an algorithm to reduce the distortion induced by the target's motion, using only 1-D stepped frequency radar signals. The algorithm estimates the kinematic motion parameters of a maneuvering target, based on subarray averaging and entropy minimization (SAEM).

ISBN: 89-86522-78-0 94460©KEES

## 2. Signal model of stepped frequency radar signals

The received signal $x_n$ from a moving target whose velocity is $v$ and acceleration is $a$, can be approximately modeled as

$$x_n = \sum_{k=1}^{L} a_k \exp\left(-j\frac{4\pi f_n}{c} r_k\right) \times \exp\left[-j\frac{4\pi f_n}{c}\left(r_0 + v t_n + \frac{1}{2} a t_n^2\right)\right] \tag{1}$$

where

$L$ : Nmber of scattering centers on a target
$c$ : speed of light, $r_0$ : Initial position of a target
$a_k$ : Scattering strength of each scattering center
$f_n$ : $n-$th measurement frequency
$r_k$ : Location of each scattering center on the local coordinate
$v$ : Velocity of a target, a : Acceleration of a target
$t_n$ : $n-$th measurement time

It should be noted that the second term in (1) is the extra phase caused by the motion of a target, and is the major source of the blurring and distortion in range profiles, as shown in Fig. 1. Therefore, the purpose of motion compensation is to estimate the target's kinematic parameters, $v$ and $a$, and to multiply the received signal model $x_n$ by the complex conjugate of the estimated second term.

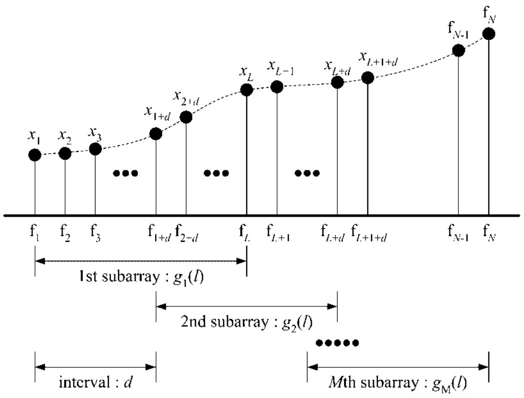

Fig. 2 The concept of subarray averaging

## 3. Proposed SAEM for 1-D stepped frequency radar signals

In order to estimate the kinematic parameters $v$ and $a$, we propose a novel cost function based on the entropy of subarray averaging as follows:

$$S = -\sum_{l=1}^{L} h(l) l\left[h(l)\right],\ h(l) = \frac{\sum_{m=1}^{M} |g_m(l)|^2}{\sum_{m=1}^{M}\sum_{l=1}^{L} |g_m(l)|^2} \tag{2}$$

where $g_m(l)$ is the $m$th range profile obtained by the inverse fast Fourier transform (IFFT) of received signal $x_n$ of the $m$th subarray. $L$ is the length of each subarray and $M$ is the total number of subarrays. $h(l)$ in (2) is analogous to the average of

$M$ range profiles obtained from $M$ subarrays. The above subarray averaging concept is illustrated in Fig. 2. As a result, the proposed SAEM estimates the motion parameters $v$ and $a$ such that the entropy $S$ in (2) is minimized.

## 4. Entropy minimization

In general, the minimization of cost function $S$ requires a computationally intensive 2-D search algorithm in a $v-a$ space. However, it can be readily shown that the constant entropy surface approximately constitutes a line in the $v-a$ plane, as shown in Fig. 3. Therefore, in order to minimize the cost $S$, we can devise a two-step 1-D line search algorithm instead of the 2-D search algorithm. First, we perform a few number of 1-D line searches along the constant velocity lines. Next, a least square fitting is applied to estimate the line equation corresponding to the valley where the global minimum point exists (see Fig. 3). Finally, an additional 1-D line search is applied along the estimated line in order to find the global minimum. In this study, the 1-D line search has been implemented via the use of combination of golden section and parabolic interpolation search algorithm. Consequently, the velocity and acceleration of the target can be effectively estimated by minimizing $S$.

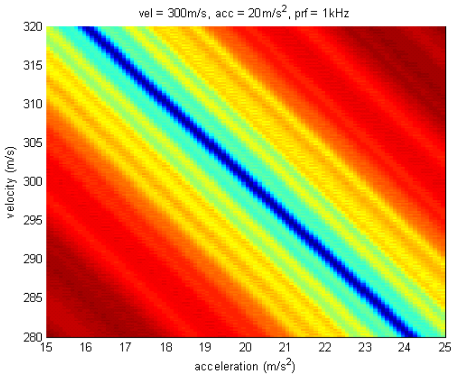

Fig. 3 Entropy cost surface when PRF is 1kHz

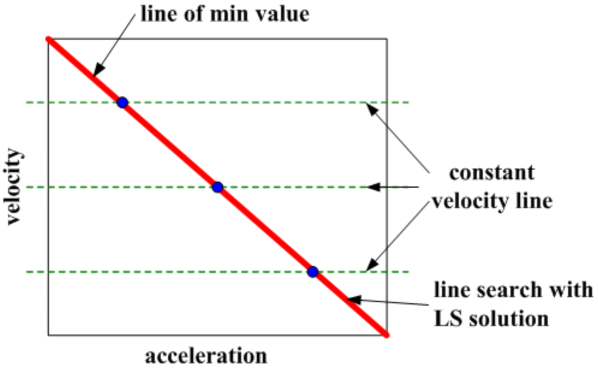

Fig. 4 combination of line search for proposed technique

## 5. Simulation results

Table 1 Parameters for radar and SAEM

| BW | $f_1$ (Initial frequency) | $N$ (# of freq. samples) | $M$ (# of subarrays) | $L$ (length of each subarray) | PRF |
|---|---|---|---|---|---|
| 512MHz | 9.0GHz | 512 | 128 | 128 | 1kHz |

In order to demonstrate the proposed SAEM, radar signals of a target consisting of 34 point scatterers are generated. The geometry of the target used in the experiment is shown in Fig. 5. It is assumed that the target is moving toward the radar with its velocity of 300 m/s and acceleration of 20 m/s$^2$. In addition, the associated parameters for radar and SAEM is summarized in Table 1. To implement the proposed search procedure, the initial search space is limited to $v$=(0,600)m/s and $a$=(-40,40)m/s$^2$.

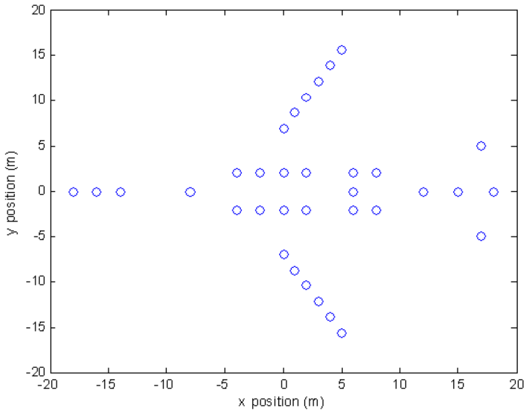

Fig. 5 A target consisting of 34 point scatterers

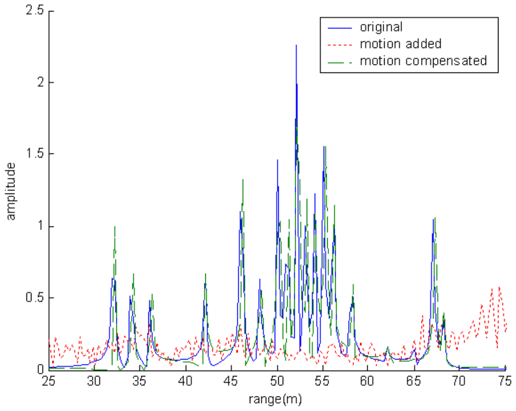

Fig. 6 Motion compensation results by the SAEM

Fig. 6 shows the motion compensation results. The solid (blue) line is the range profile when the target is fixed with no motion. The dashed (red) line shows the distorted range profile arising from the target's motion with $v$=300m/s and $a$=20 m/s$^2$. We can easily notice that the range profile is severly distorted such that its behavior is nearly noise-like. The solid and dashed (green) line is the motion compensation results via the use of the velocity and acceleration estimated by the proposed SAEM. It can be readily identified that the reconstructed range profile shows a good agreement with the range profile with no motion.

## 6. Conclusion

A novel motion compensation technique called SAEM has been developed and verified. It is shown that the proposed scheme on the basis of subarray averaging and entropy minimization, can successfully reduce the motion-induced distortion included in the 1-D stepped frequency radar signals. The proposed SAEM is very useful especially for radar target identification using 1-D range profiles of a target [3].

## 7. References

[1] B. C. Flores, J.-S. Son, and S. Tariq, "Efficient method for the translational motion compensation of inverse synthetic aperture radar imagery," *Opt. Eng.*, vol. 40, no. 3, pp. 433-442, March 2001.

[2] J.-S. Son, G. Thomas, and B. C. Flores, *Range-Doppler Radar Imaging and Motion Compensation*, Artech House, 2000.

[3] K.-T. Kim, D.-S. Seo, and H.-T. Kim, "Efficient radar target recognition using the MUSIC algorithm and invariant features," *IEEE Trans. on Antennas and Prop.*, vol. 50, no. 3, pp. 325-337, march 2002.