Application of the new algorithm ISAR-GMSA to a linear phased array-antenna

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Résumé: Dans cet article, nous présentons l'application de l'algorithme ISAR-GMSA (Inverse Synthetic Aperture Radar-Generalized Multiple Scatterer Algorithm) à des données réelles. Nous avons utilisé un système de réception à une antenne et une antenne-réseau pour montrer l'amélioration du réseau sur l'élément simple.

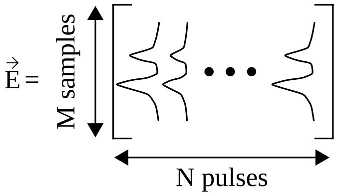
Abstract: In this paper we present the application to real targets of the new ISAR-GMSA (Inverse Synthetic Aperture Radar-Generalized Multiple Scatterer Algorithm) algorithm for radar imaging. We applied the algorithm to a single antenna receiver and to a phased array-antenna system to show the improvement of the array over the single antenna system.

Introduction

The ISAR-GMSA (aka ISAR-RMSA: ISAR-Recursive MSA) algorithm has been developped by H.Wu . This algorithm synthetizes a dominant scatterer from (I+1) non-dominant scatterers in order to set the phase of the synthetic aperture. Each non-dominant scatterer is considered inversely to its variance to lower the variance of the resulting phases in the aperture and then improving the focus of the aperture. We present, for comparaison, the usual algorithms such as DSA (Dominant Scatterer Algorithm) and MSA (Multiple Scatterers Algorithm).

The ISAR-GMSA algorithm

To build the synthetic aperture, the datas are stored in the matrix E. The n-th column of the matrix E contains the M samples of the n-th pulse return and then, each row shows the history of a scatterer (see Figure 1). But the phase of the elements are still distorded by the target translation motion and the perturbation on the speed and traject. Thus the phase must be corrected. If there is only one dominant scatterer, the DSA algorithm may be applied. There exist a suitable scatterer in only 80% of experiments . If there is 2 dominant scatterers, the MSA algorithm may be used, but it occurs much less frequently.



$$\vec{E}_{mn} = A_{mn} e^{j\phi_{mn}}$$

Figure 1 Data Matrix

To be consider a prominent scatterer, it should be smaller than the cross-range resolution and its echo strength must be stronger than the total backscattering from all the other scatterers. In this algorithm, the dominent scatterers are selected based on the variance of the constant range range-bins, which must be smaller than 0.12 (refering to a normalised variance). Once the (I+1) least variant range-bins have been identified, the phase of the received samples can be compensated by the following:

$$\phi_{n_{GMSA}} = \frac{1}{S}\sum_{i=0}^{I}[\phi_{in}]^{u}w_{i} . \tag{1}$$

The superscript u means “unwrapping” , the underscript n indicates the length of the vector at a constant range m and w_i is a weight factor. The factor w_i depends on the technique applied and S is the sum of all the weigthing factors. To ease the phase unwrapping, the last equation may be rewrite as in (2), which is the RMSA approach,

$$\phi_{n_{RMSA}} = \phi_{0n} + \frac{1}{S}\sum_{i=1}^{I}[\phi_{in} - \phi_{0n}]^{u}w_{i} , \tag{2}$$

where ϕ_{0n} stands for the phase vector of the first dominant range-bin and ϕ_{in} stand for the phase vector of the ith scatterer. Choosing the weigthing factor properly, one can found the DSA and MSA algorithm, as shown in the next two equations (weight factors are zeros for DSA and ones for MSA). Setting the factors inversely proportionnal to the variance of the constant range range-bins, one get the RMSA algorithm which is applied to our measurements. The following two algorithms will be applied as comparaison for the RMSA algorithm.

$$\phi_{n_{DSA}} = \phi_{0n} , \tag{3}$$

$$\phi_{n_{MSA}} = \phi_{0n} + \frac{1}{I}\sum_{i=1}^{I}[\phi_{in} - \phi_{0n}]^{u} . \tag{4}$$

The DSA algorithm may be apply in most cases, as stated by Steinberg , so it can be the first step of the recursively built compensation phase vector. The vector ϕ_n will focus the aperture in cross-range, showing the target in the middle of the image. In order to simplify the phase unwrapping, the phase linear slope is estimated by a FFT and removed from the initial phase vector. This has the avantage to avoid the negative effects of shadowing and frequency perturbations.

The focus in range is performed in real time by the range tracking of the Kalman filter. For each pulse, the recording window is moved in space so the target will fall in the same constant range-bins. For the angular tracking, the algorithm also uses a Kalman filter which is based on the differential phase shift between two sensors.

The cross-range processing is simply performed by a inverse FFT which in inherent to the beam-stearing of the aperture.

The MSA algorithm may not be useful when the target shows only 1 dominant scatter. Targets showing 2 dominant scatterers are not usual so it is obvious that another algorithm is necessary to focus properly signals that don't show 2 dominant scatterers. This is the main innovation of the ISAR-GMSA algorithm .

Single antenna receiver system

First of all, we applied the algotihms to a single antenna receiver to show the results of the GMSA compared to the MSA and DSA. The target used is described in the next figure. It is a 20m sided pentagram and it shows 20 scatterers, with only one dominant scatterer, scatterer #1.

Array-antenna receiver system

To improve the quality of the radar signal, it may be helpful to consider a phased array-antenna. Combining 8 signals by simple vector addition and then using an imaging algorithm, it should produce a higher quality image. Considering a DOA α from the radar LOS, which is a fonction on time, and E_k the complex signal received at the element k of the array, the total signal is

$$E_T = \sum_{k=1}^{K} E_k e^{j\beta(k-1)d\sin(\alpha)} , \qquad (5)$$

where $\beta = 2\pi/\lambda$ and d is the element spacing. For the sum to be meaningful, the estimated range, done by the Kalman filter, must be the same for every antenna. Because the target may not fall in the same range-bin from an element of the array to another, it is necessary to realign the antennas in the way that they show the same dominant scatterers at the same constant range. As expected, the total signal has a much lower variance, so that it allowes us to apply the MSA when it was not possible before.

If the target is far from the radar, the DOA of each element is the same, but with our laboratory radar, this is not the case because the target is 3 meters away. It will be necessary, in (5), to make the DOA α a fonction of also the position of the elements because the target cannot be considered far from the array-antenna. Using 8 elements allows us to improve the angle tracking done by the Kalman filter. Doing so, the DOA may be estimated more accurately.

The algorithms have been tested for the 2 systems decribed before with both numerical simulations and experimental datas from our laboratory radar system.

Numerical results

The target used for simulations is described in Figure 2. For these numerical simulations, we place the target at an initial range of 20km and at a constant speed of $250 \mathrm{m/s}$. The target travels at $\gamma = 60°$ from the radar LOS from an angle of arrival of $\alpha = 30°$. Recording 800 pulses, it allows an aspect angle change of 1.17° and gives a cross-range resolution of 1.35m. The image cells are 0.525m in range and 0.656m in azimuth. The elements of the array are 1m apart.

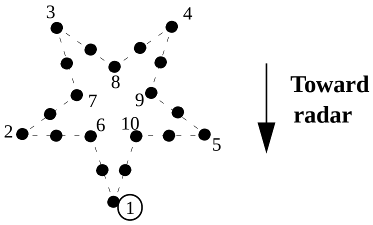


Figure 2 Geometry of the pentagram target

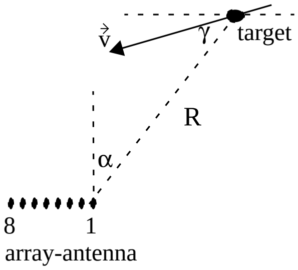


Figure 3: Geometry of the system

Single antenna receiver

The Figure 5 shows cleary that the GMSA algorithm improves the results from the MSA algorithm even when the second scatterer used in the phase compensation is not dominant. The GMSA succeeded where the MSA failed: the target is centered more precisely and the backscattering noise is lower.

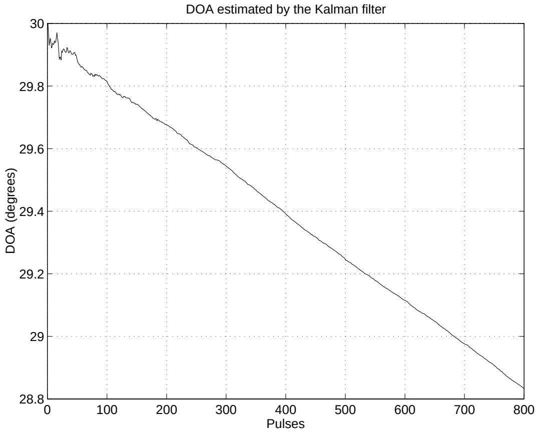


Figure 4: Estimation of DOA by the Kalman filter

Array-antenna receiver

In Figure 4, we can see that the DOA is correctly estimated by the Kalman filter using only the first two elements of the array. For the few first pulses, the filter needs to lock on and once it is done, il follows the target very well. To work properly, the Kalman filter needs a large phase shift which occurs when the elements are far apart. For a smaller array-antenna, instead of using two consecutive elements, one may use the first and the sixth elements, for example, to track the target. We may also average the results over a few elements sub-array.

For the array-antenna receiver, as showed in Figure 6, we see that the quality of the images has improved greatly by combining the signals of the array, as expected. The signal-to-noise ratio of the total signal is 18 dB higher than the SNR of a single element signal, meaning that the phase aligment is performed correctly.

Experimental data processing

To verify our conclusions, we used experimetal datas. The target is made of two metallic plates of 10x10cm, as shown in Figure 7. The radar used is the Lab-Volt radar system that modulates pulses of 1 ns at 9.4 GHz. The target is at an initial range of 2.5m and travels at a speed of 1.44 m/s. The physical properties of the radar antenna allows to record 50 pulses with a PRF of 288 Hz, which gives a cross-range resolution of 0.377m with a cross-range bin size of 0.020m and a aspect angle change of $4.1°$.

To allow the computer to save the datas, the acquisition can not be performed is continous movement. The target must move with discret steps, each step corresponding to a constant speed movement. Because the target remains still during the acquisition, we may subsample the pulse return with a ratio of 1024 to get a high equivalent sample rate.With 150 points per pulses, we get a 0.010m range-bin size. The initial angle of arrival is $\alpha = 3°$ and the direction angle is $\gamma = 45°$ for the approaching targets (images 13 and 17) and $\gamma = 135°$ for the outgoing target (image 22).

Single antenna receiver system

The results are showed in Figure 7 and Figure 7. Those are raw images, no image enhancing techniques have been used. We see that, the MSA and the GMSA algorithms give similar results, simply because the two most prominent scatterers have a very similar variance (see Table 1). In that case, MSA and GMSA are the same algorithm and they give a nice image.

Table 7: Dominant scatterers and their variance

Images	#1	var(1)	#2	var(2)
13	96	0.125	50	0.137
17	24	0.150	68	0.153
22	61	0.048	65	0.055

Array antenna experimental data processing

Results will be presented at the conference.

Conclusion

We applied the GMSA algorithm to real datas from our laboratory. We used simple targets approaching and outgoing the radar with both a single antenna receiver and an array-antenna receiver. We may conclude that the single antenna algorithm gives good results if the signal has a strong enough SNR to show the dominent scatterers. Otherwise, this caracteristic may be improved by an array-antenna to get a much better image.

References

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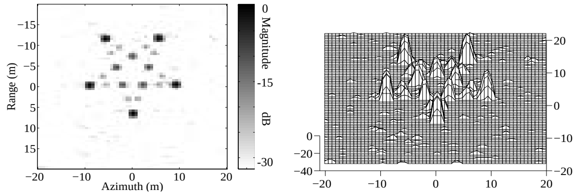
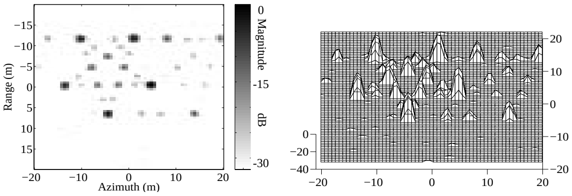
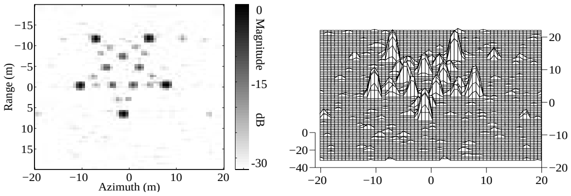


a) DSA

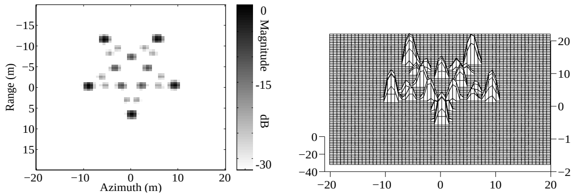


b) MSA

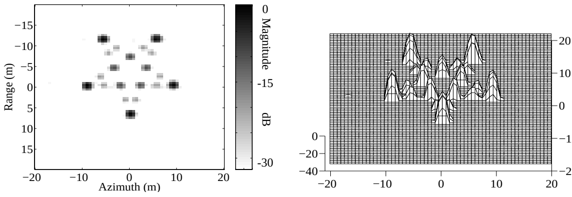


c) GMSA

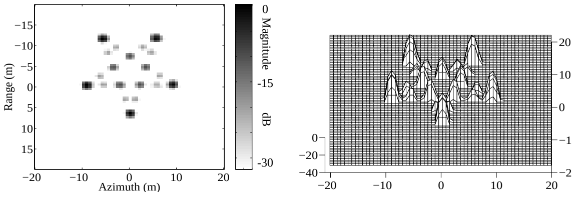
Figure 5: Images, intensity and density, with a single antenna receiver



a) DSA

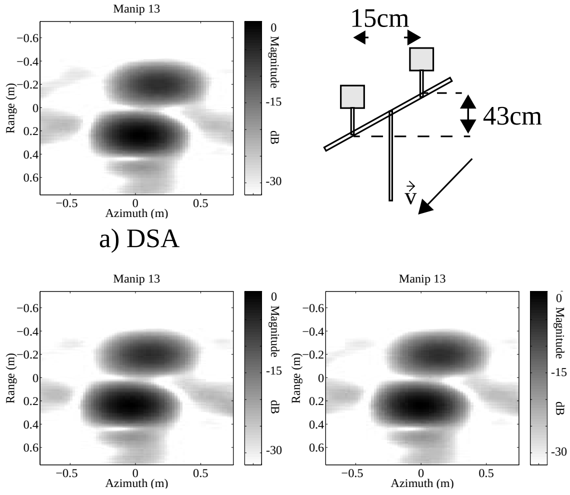


b) MSA



c) GMSA

Figure 6: Images, intensity and density, with a phased-array antenna of 8 elements (d=1m)

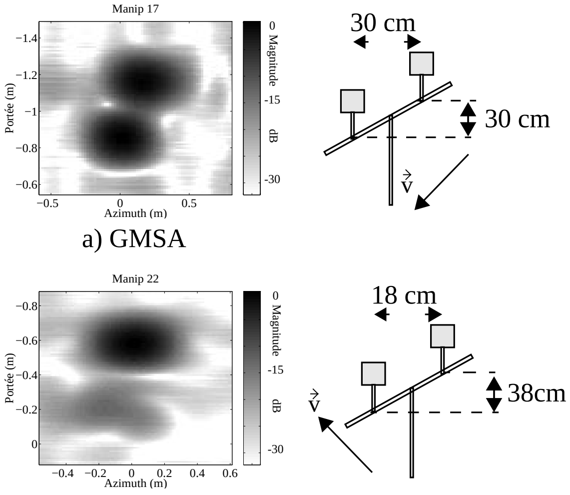


a) DSA

b) MSA

c) GMSA

Figure 7: Experimental images from real data, provided by a single antenna receiver



a) GMSA

b) GMSA

Figure 8: Experimental images from real datas, provided by a single antenna receiver