SYNTHETIC APERTURE RADAR DEMONSTRATION KIT FOR SIGNAL PROCESSING EDUCATION

(1)François VINCENT, (1)Bernard MOUTON, (2)Eric CHAUMETTE, (1)Claude NOUALS and (1)Olivier BESSON

(1) ENSICA, Toulouse, France – {vincent, mouton, nouals, besson}@ensica.fr
(2) Thales Air Defence, Bagneux, France – eric.chaumette@fr.thalesgroup.com

ABSTRACT

A Synthetic Aperture Radar scale model has been developped to improve signal processing teaching. Based on low frequency ultrasound transmission, it is a low cost demonstration kit. The overall software is directly running on Matlab® and allows easy and realtime modifications. This educational tool can be used to test different waveforms and show the effects of a real scene on the final image. It can also be used in a more advanced way to test different signal processing in order to improve image focusing or to reduce computation burden.

***Index Terms*—** Educational technology, Synthetic Aperture Radar, acoustic applications.

1. INTRODUCTION

Environmental monitoring, earth-resource mapping and military systems require broad-area imaging at high resolution. Many times the imagery must be acquired in inclement weather or during night. Synthetic Aperture Radar (SAR) provides such a capability [1]. SAR systems take advantage of the long range propagation of electromagnetic field and of the complex information provided by the emitted coherent wave. Thus, they complement optical imaging capabilities because of their ability to view at night and through clouds, fog, dust, adverse weather and, in special circumstances, foliage and the ground itself (land-mine detection).

A SAR image corresponds to a two-dimensional map of the radar reflectivity of a target scene wich includes real metric distances. Because of the unique responses of terrain and cultural targets to radar frequencies, the SAR image provides a different information compared to optical or infrared systems. For instance the backscattered energy from a ground scene depends on its water proportion because of its dielectric properties. Moreover exploiting the phase information contained in the received signal, it is possible to compare two images of the same scene and to detect small position changes or to measure very precisely the third dimension of the map (interferometric SAR). Hence, Synthetic Aperture Radar is used for a wide variety of environmental applications, such as monitoring crop characteristics, deforestation, ice flows and oil spills. SAR systems are generally mounted on a plane or on a satellite.

A classical pulse compression radar transmits a series of frequency modulated pulses. For usual pulse duration and frequency repetition, the range-velocity processing consists of two different operations. The range of a detected target is calculated from each echo using a correlation with the transmitted pulse (pulse compression) and its speed is estimated by the phase shift from pulse to pulse (doppler filter). In a SAR system, signal processing is similar. All targets in the illuminated scene are supposed fixed and the radar is moving. The range of all targets is calculated using pulse compression and their doppler characteristics are used to artificially narrow the antenna beam in the orthogonal direction. Indeed, knowing the position of the radar antenna at each pulse, it is possible to compensate for the phase shift due to the displacement and to sum up the multiple returns of each target. The resulting resolution is the same as if we'd used an antenna whose size is commensurate to the total displacement of the radar during the processing.

The Faculty staff at ENSICA, Toulouse, France has developped a SAR demonstration and evaluation toolkit to improve teaching of such a complex imaging system. For cost and practical reasons, we choose to use UltraSound (US) waves instead of electromagnetic ones. Indeed, because of the low propagation speed of sound pressure waves (c=340 m/s in the air at 20°C), we can keep the wavelength and the range resolution in the same order of magnitude as for real radar systems, using lower frequencies (~40 KHz). We can then use standard and low cost electronics and digital acquisition cards. Moreover the amount of data is reduced and can be easily processed by a usual personal computer (PC). Nevertheless, the system structure, the transmitted waveform and the processing are kept similar to real life systems.

The paper is organized as follows. Section 2 presents the hardware structure of our scale model. Then signal processing methods are described in section 3 as well as the educational exploitation we make. Section 4 contains concluding remarks.

2. HARDWARE STRUCTURE OF THE SCALE MODEL

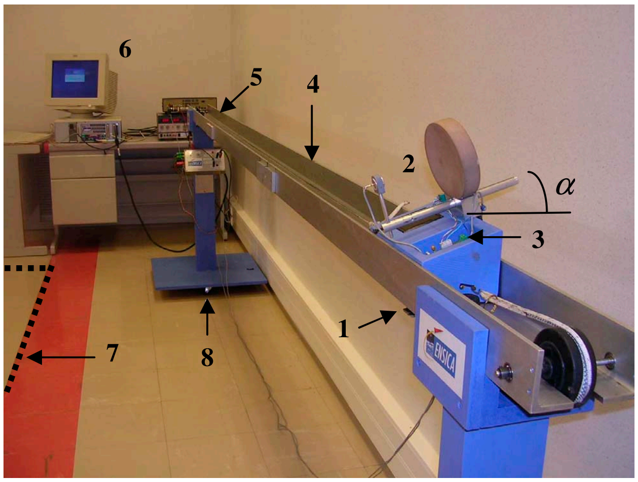

Fig. 1 demonstration kit overview

Our demonstration kit is a scale model of a Side-Looking Airborne Radar (SLAR) [2] as shown in figure 1. The moving part of the system is composed of a wideband US transmiter (Pro-wave 400WB160 - **1**), a parabolic reflector (diameter D = 10 cm) with the above mentioned sensor in its focus (**2**) and a narrowband analog amplifier (**3**). The pitch angle of the beam antenna is $\alpha = 15°$. This part is moved along a 3 meter metallic rail (**4**) by a DC motor (**5**) to ensure a linear displacement with constant speed (~25 cm/s). Transmitted waveforms, received signals and motor commands are all handled by a usual PC (**6**) using Matlab® Data Acquisition Toolbox equipped with a National Intruments® acquisition card (PCI-6024E).

The transmitted signal is composed of a series of N linear frequency modulated pulses (chirps) as shown in figure 2. We only use real (in-phase) signals. The waveform parameters can be chosen by the user. Classical values are

$$\begin{cases} B = 4\ KHz \\ T = 5\ ms \\ T_r = 30\ ms \\ F_p = 40\ KHz \end{cases}$$

where B is the frequency span, T is the pulse duration, T_r is the pulse repetition time and F_p is the carrier frequency.

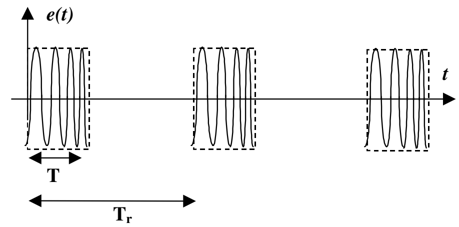

Fig. 2 transmitted signal

With these typical values, the signal wavelength, $\lambda = c/F_p$ is 8.5 mm which is typical of radar systems operating in the Ka band. The received antenna beamwidth, $\theta = \lambda/D$ is approximately 5 °. The illuminated area (**7**) is a ground rectangle of size 3 by 1 meters. The theorical cross track resolution, Δx and along track resolution, Δy are given by [3] :

$$\Delta x = \frac{c}{2B\cos\alpha} = 45mm \quad \Delta y = \frac{D}{2} = 50mm$$

3. SOFTWARE DESCRIPTION AND EDUCATIONAL USE

The software part of the demonstration kit is composed of Matlab functions, each of them corresponding to a specific task, as shown is figure 3.

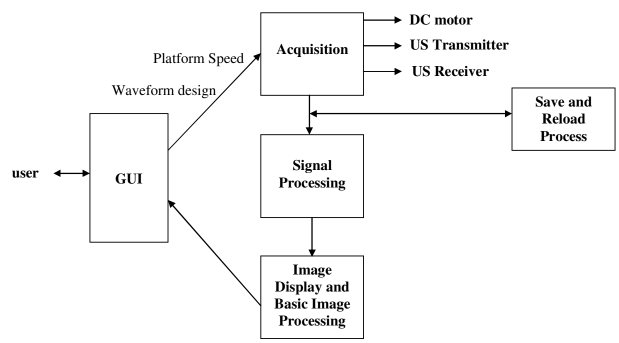

Fig. 3 Software structure

- The acquisition block drives the interface card in order to pilot the radar speed, to send the waveform and to sample the received signal.
- The signal processing block reshapes the data before proceeding to SAR processing. This processing consists of a correlation on each received pulse with the transmitted signal (pulse compression) to compute the cross range of the targets. Then synthetic aperture processing is applied from pulse to pulse in order to focus the targets in the along track.

- The image display block allows to plot the resulting reflectivity map in different ways (3D view or colormap view). Basic image processing procedures such as thresholding can be applied to improve the displays interpretation.

The overall matlab functions are linked by a Graphical User Interface (GUI) to allow a quick change in the experiment parameters (figure 6 and 7).

The educational exploitation of the SAR model could be done at two different levels.

§ For basic courses on radar systems and radar imagery, the students use the experiment in order to understand the impacts of the waveform parameters on the final image. The students have to observe the effects of changes on the signal bandwidth (effects on the cross track resolution), on the pulse duration (increase of blind zones), on the pulse repetition frequency (PRF) (effects on the max-range but also on the Doppler effect). They have to observe that the PRF must be acurately chosen with the system speed and the radar beamwidth in order to avoid doppler ambiguities and ghost targets in the final display. Choosing a too high PRF avoids doppler aliasing effects, but increases range ambiguities and could lead to range ghost targets because of the sidelobes of the antenna beam.

The students can also observe the effects of the usual SAR processing, in particular the impulse response of the system showing the sidelobes of the chirp autocorrelation function. They can also observe the effects of the non uniform illumation of the beam antenna on the ground and more generally the differences between the theorical and the experimental results, especially concerning the system resolution.

To finish with, they have to calculate an adapted waveform to a given ground scene to be imaged. The ground scene is composed of one type of target. The targets are small usual 8-pin DIP integrated circuit (10×5×3 mm) such as TL071 as shown in figure 4. Figure 7 shows an exemple of the result obtained from the real scene represented in figure 5 as viewed by the radar. We can see in figure 6, the raw image (echo amplitude without processing), the image after the pulse compression step and the final image in figure 7.

Fig. 4 experimental target

Fig. 5 real scene view from the radar path

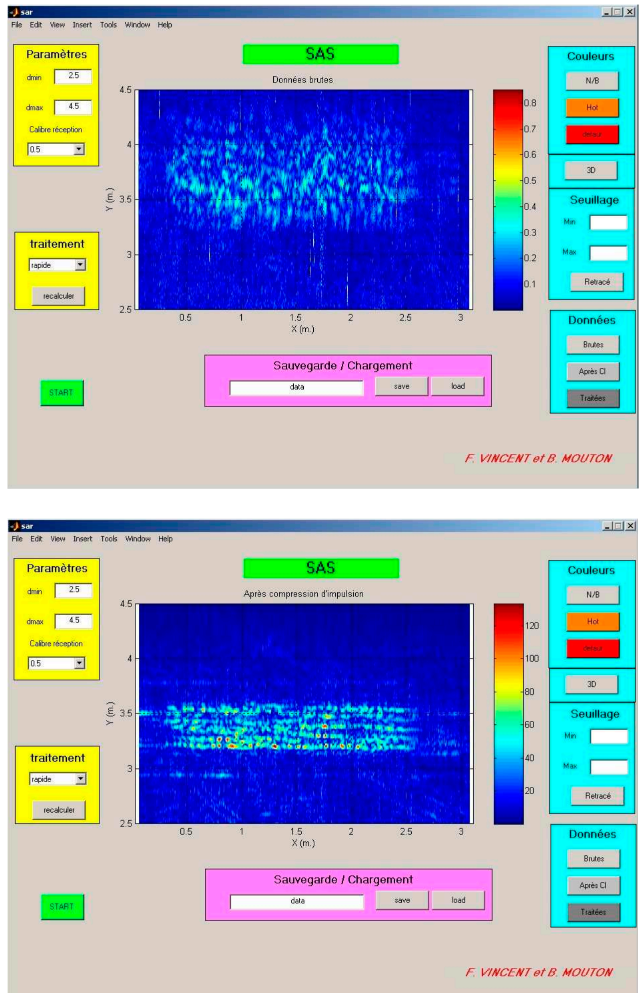

Fig. 6 raw and after pulse compression image

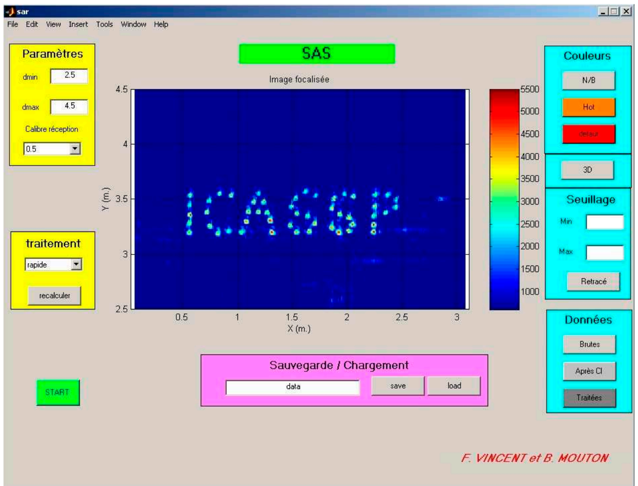

Fig. 7 final reflectivity map and GUI display

§ For advanced courses on SAR processing, the students have to program their own signal processing functions. The goal of this approach is to understand the effects of the signal model both on the final image and the processing time. Indeed the optimal SAR processing consists of a correlation with the model echo response for all ground positions. But for the sake of simplicity, two main approximations are usually made. First we suppose that the Doppler shift is constant during the pulse duration and is only changing from pulse to pulse. This approximation allows to separate range processing from doppler processing. Second, we assume that the doppler shift is linearly dependent on time, which comes from an approximation of the radar-target distance during illumination time. The students have to derive the optimal processor, to observe the gain on the final image and to calculate the extremely higher computation burden. They can then improve the basic processing using for instance Fast Fourier Transforms.

Moreover, the demonstration kit is all mounted on rollers (figure 1 – **8**) allowing to disturb the nominal flightpath of the radar. The recorded data corresponds to the real case where the plane or satellite path is not perfectly known or has been disturbed by a vibration. The students have to observe the effects of the different perturbation movements on the final image. Across path disturbations induce doppler defocusing and along path disturbation could result in a wrong position of the targets. The students can then try to compensate the unknown part of the path using autofocus algorithms such as the phase gradient algorithm [4] [5] [6].

4. CONCLUSIONS

In this paper we have described an original teaching method for radar signal processing education using a SAR demontration kit. This tool has been developped in a low cost aim using low frequency ultrasounds instead of electromagnetic microwaves. We can then use common electronic circuits, wires and digital acquisition cards. Moreover the overall software structure is directly programmed using Matlab®. Direct modifications can then be tested by the students. The aim of this experiment is twofold. It can be used as a simple tool to optimize the choice of the parameters waveform for a given environment. Or the students can modify the basic software to improve processing performances (reducing computation burden or improving image quality). Finally this tool could be used to test autofocus SAR algorithms.

5. REFERENCES

[1] J.C. Curlander and R.N. McDonough, *Synthetic Aperture Radar: Systems and Signal Processing*, New York: Wiley, 1991.

[2] J.C. Jakowatz, D.E. Wahl, P.H. Eichel, D.C. Ghiglia, and P.A. Thompson , *Spotlight Mode Synthetic Aperture Radar: A Signal Processing Approach*, Kluwer, Boston, 1996.

[3] P. Lacomme, J-P. Hardange, J-C. Marchais, and E. Normant, *Air and Spaceborne Radar Systems An Introduction*, William Andrew publishing, New York, 2001.

[4] V.C. Koo, T.S. Lim, and H.T. Chuah, *A comparison of autofocus algorithms for SAR imagery*, Progress in electromagnetics research symposium 2005, Hangzhou, China, August 22-26.

[5] P. Eichel, D. Ghiglia, and C. Jr Jakowatz, *Speckle processing method for synthetic aperture radar phase correction*, Optics Letters 14 20, October 1989.

[6] D. E. Wash, P. H. Eichel, D. C. Ghiglia, and C. V. Jakowatz Jr, *Phase Gradient Autofocus – A Robust Tool for High Resolution SAR Phase Correction*, IEEE Transactions on Aerospace and Electronic Systems Vol.30, N°3, July 1994.