Real time SAR Simulator Design

Artur Tadevosyan

Institute for Informatics and Automation Problems NAS RA,
Yerevan, Armenia
e-mail: astadevosyan@gmail.com

ABSTRACT

Synthetic Aperture Radar (SAR) creates the effect of a very long antenna by analysis of signal properties. Simulators play an important role in the initial phases of developing SAR Processing Modules (SPM). They make improving theories, testing new or developing concepts easier, faster and less expensive. This article describes an instance of real time working SAR simulator, which is in operation. The basics of how it works, types of data transfers, and comparative analyses of working modes are shown.

Keywords

Synthetic aperture radar (SAR), real-time computing (RTC), simulator, radiolocation, analog-to-digital converter (ADC), digital-to-analog converter (DAC)

1. INTRODUCTION

There are a few different methods of operation for SAR systems. The described simulator allows debugging and developing several types of SAR systems such as Stripmap, ScanSAR [1]. In a standard monostatic architecture, SAR is composed of a platform (i.e. airborne or satellite) with the same antenna for the transmitter and receiver [2]. While the platform passes over the scene, the antenna transmits a series of EM pulses and recollects backscattered radiation (echo) [3]. In the SPM, the received signals are processed together by coherent combination [4] after the accumulation. The accumulation is the storage of a certain amount of sequential received echoes (later echoes), which contain a reflected signal of the transmitted pulse. The data is stored within a single accumulation called a pack. One image is obtained from a single pack. The processing begins after all echoes have been stored. Therefore, this means that the process can be divided into two sequential stages: accumulation and processing. It follows that it is possible to design two different working modes of real time simulator:

- Echo-providing mode,
- Pack-providing mode.

In the echo-providing mode, every output represents a signal corresponding to the echo. This mode is closer to the real conditions. In this case, SPM has to read and store every echo separately and thereafter start processing. To an echo with a duration T correspond N_T digital values (1). For instance, in a system using 250 MHz sampling rate and 70 µs pulse repetition interval (PRI), the echo will contain 17500 values. However, the amount of received values in one echo in SPM does not match with the PRI duration. It receives less information. This is due to the turned off receiver during transmission [5], abilities of Analog Digital Converter (ADC), and the size of targeting area. To maintain similarity with the real conditions, the simulator also has the capability to provide a lesser amount of values N ($N \leq N_T$).

In the pack-providing mode, the simulator outputs data corresponding to a single pack. In this case, SPR can start processing immediately after reading, omitting the accumulation stage. The amount of digital values (N_{arr}) depends on the number of echoes in one pack (M) and the number of values in the pack (2). For instance, in a system using 250 MHz sampling rate, 70 µs PRI, 16384 values in echo and 1.05s accumulation time (T_{arr}) the output will contain 245.76 millions of values (3).

$$N_T = F_s T \quad (1)$$

$$N_{arr} = NM \quad (2)$$

$$N_{arr} = N(T_{arr}/T) \quad (3)$$

Where F_s is data sampling rate.

2. SIMULATION FLOW STEPS

The simulation flow can be implemented through performing the following three steps:

1. Precomputing,
2. Computing,
3. Using.

The Precomputing and computing steps together compose the generation stage. In pack-providing mode, the first step starts with precomputing, followed by the step of computing M times and finally using. In the echo-providing mode after precomputing, steps 2 and 3 are repeated cyclically M times.

Precomputing: There is data in the signal generation process, which is common for resulting data in different moments of time. Processing this data only once, it is possible to avoid a waste of computational resources. For this reason, the precomputing step is separated. The data processed at this step is divided into two parts: common in pack and common in echo.

Common data in echo is the data, which is the same in all echoes. These include probing signal, amplitudes obtained from input image, etc.

Common data in pack are clutters [6] with a specific distribution function [7]. This data is unique to echoes in the same pack, but can be used multiple times (means use multiple times in different packs) in several packs. The size of this data is M times bigger than common data in echoes.

Computing: The resulting data is finally generated in the computing step. This step uses data generated in precomputing. The whole computing step is divided in the following substeps:

1. Platform's current position calculation
    1.1. Basic positon calculation,
    1.2. Platform fluctuation*,
2. Echo generation,
3. Adding extra signals,
    3.1. Adding clutters*,
    3.2. Adding jammers*.

* - these substeps are optional.

1.1. The formation of a synthetic aperture requires a coherent phase history to be maintained during the time. It takes the platform to traverse the synthetic aperture. Up to this point we have considered the motion of the platform to be perfectly rectilinear [8]. The basic current position of the platform is calculated by the assumption that the motion is rectilinear, uniform, and parallel to the ground. Let us assume the platform's motion is parallel to x axis. The basic position $P_i(x_i, y_i, z_i)$ for the current echo equals $x_i=x_0+vt_i$,

$y_i=y_0$, $z_i=z_0$. Where t_i = i*T is time of the current echo, T - PRI, i - the number of echo, $P_0(x_0, y_0, z_0)$ – the platform's initial position, v – platform velocity.
1.2. In a realistic situation, the imaging platform is subject to motion perturbations [8]. There is fluctuation during flight, which comes from the platform specifications, weather conditions, etc. As a result, current position differs from basic current. This creates problems during processing in SPM, such as phase errors [9]. To solve these problems there is a feature to allow for a fluctuation in the platform motion. The fluctuation can be trigonometric or random in x, y, z axes.
2. On this step occurs the generation of the informative signal. The source data describing the targeting area can be one or several targets, or an input image. The main difference between an image and target as a source is that an image covers the whole targeting area with a defined precision, while a group of targets represents specific positions in area. The mostly used source is an input image. The mathematical model, where the algorithm for the simulation based on input image is represented in [10].
In the case of targets, every target has several input parameters, such as radar cross section of the target (σ), distance from the transmitter to the target (R). For every target linear frequency modulated pulse is generated with a power (P_r) obtained from radar equation (4).

$$P_r = \frac{P_t G_t A_r \sigma F^4}{(4\pi)^2 R^4}. \tag{4}$$

Where P_t - transmitter power, G_t - gain of the transmitting antenna, A_r - effective aperture of the receiving antenna, F - pattern propagation factor,
The pulse shift in the echo signal depends on the time delay (Δt) from transmission to reception. It is related to the speed of the propagating wave and the distance from antenna to object (5):

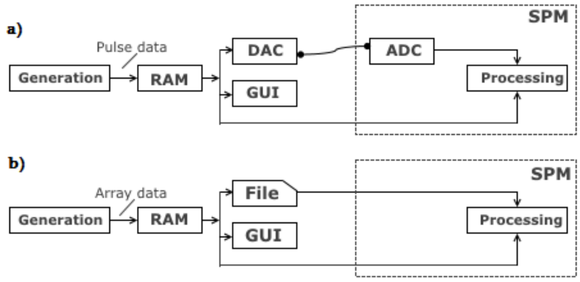
$$\Delta t = 2R/c \tag{5}$$

Where c is light speed.
Then, generated echoes for every target adding element-wise.
3. Radar echoes are a mixture of wanted (informative) echoes and clutter echoes (often from sea, weather, birds, etc.), which are generally of no interest [11]. Nevertheless, clutters may interfere with processing. It means that after successfully processing (making a picture) informative signals, SPM should improve its processing, such as being able to keep working, even in a presence of clutters. In addition, the simulator also allows the addition of jammer signals (6). Signals of clutters and jammers are optional. The user can turn them on or off. This allows the SPM developer to test the module in different conditions.
In contrast to informative signals, clutter and jammers signals are mostly generated in precomputing step. The summary signal for an echo equals to:

$$P(k)_i = \sum_{j=1}^{L} J(k)_{(i,j)} + B(k)_i + S(k)_i, \quad i = \overline{1,M} \tag{6}$$

Where P - echo signal, J – jammer signal, B – informative signal, S – clutter signal, k – index of echo, i – index of value in echo, j – index of jammer, L – number of jammers, M – echo number in pack.

Using: The data generated in generation stage can be used in several ways:
- Storing in memory,
- Transferring to DAC,
- Showing on display.

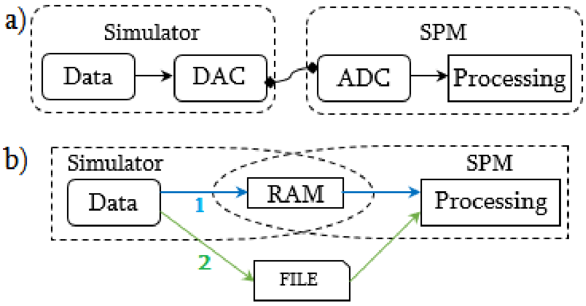


Picture 1. Using ways in a) echo mode, b) pack mode

The total spent time for precomputing and computing in echo-providing mode can exceed PRI. This situation can happen during increasing processing data size. It depends on some input parameters, such as sampling rate, number of values in echo, dimensions of input image, etc. At this time, real time working has an initial delay. It means that before passing to using step (starting to work with SPM), the simulator should generate data in advance for supporting real time data providing in using step. This stage is called pregeneration. In the generation stage, the system works as if it is in pack-providing mode. After the precomputing step follows M times computing. The difference is that echo-providing mode with a pregeneration can work DAC, providing an analog signal to SPM.
The initial delay problem can also happen in pack-providing mode, but the pregeneration stage as such is not separated. The same flow continues, but is given a warning that more time will be required to finish the generation.

3. SIMULATOR-SPM DATA TRANSFER

Simulator is a tool for SPM. Therefore, it is important to design practical interface between them. For transferring data from simulator to SPM, several options are designed:
- Analog with a cable,
- Digital with RAM,
- Digital with a file.



Picture 2. Simulator-SPM data transfer, a) analog, b) digital

Analog is the closest option to real conditions (pic. 2, a). There were used analog tools to transfer data. After generation of digital data, the simulator converts it to analog by DAC. The output of DAC is connected with the input of Analog Digital Converter (ADC), which is the part of SPM. SPM starts processing after getting digital values from ADC. The advantage of this data transfer type is the opportunity to check the whole functionality of SPM. This means simultaneously checking problems with algorithms, channels, cables, and conversions.
Receiving digital values SPM works in a simpler mode without using tools for receiving, and converting analog signals. This allows SPM to debug avoiding the ADC inaccuracy, and problems with cables.
On the example presented in pic. 2, b-1, the simulator and SPM have shared RAM. Common access allows SPM to

work with data without copying them. The advantage is a quick data transfer.

On the example presented in pic. 2, b-2, SPM reads data saved before. The advantages are the possibility to work with data generated in the past, periodic work on the generated data based on the same input parameters, transferring data over distances.

Each of options has its own advantages and disadvantages (table 1). Based on the problem can used be used any of them. The comparative analyze of them represented in the table below:

	Real conditions	I/O simplicity	I/O speed	Multiple usage
Analog	+	-	+	-
RAM	-	+	+	-
File	-	+	-	+

Table 1. Comparison of Simulator-SPM data transfer ways

In the initial stages of developing, it is recommended to use digital signals. In the case of using the same simulation signal multiple times, it is preferable to save data in a file. It will allow for use the next times without wasting time for new generation. For the checking system operation for different input parameters, it is desirable to use shared memory. This will allow for us to save the time spent on writing, and reading on ROM. In the final stage of SPM, initial testing need to be checked by analog transfer option. This will allow for checking inaccuracies with the data transfer.

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