Current development status of MiniSAR, an Italian airborne interferometric SAR

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Abstract

This paper reports on development status of MiniSAR, a compact airborne interferometric SAR, oriented to production of technical topographic maps, for monitoring landslides evolution and for assessing their extension and risk area. Particular efforts have been devoted to limit its dimensions and mass, to allow its installation on board of ultra-light aircraft, but without jeopardizing performance. MiniSAR main design choices and expected performance are described.

1 Introduction

Among natural hazards, it is especially for floods and landslides that airborne SAR systems can play a key role mainly for their capability to provide high resolution, all-time and all-weather observations. The goal is not only to investigate the damages but also to give warning, evaluate the risk and prevent catastrophes.

To this aim essential information arise from accurate topography of the area in addition to the possibility to monitor small movement of control points on ground with high degree of precision (of the order of 1 cm or less). Essentially, it is what classical and differential airborne SAR interferometry can offer [1-2]. To this end several research teams have been developing and experiencing airborne SAR interferometric systems during recent years [3-9].

In this framework the Italian Ministry for Education, Universities and Research (M.I.U.R.) co-funded the MiniSAR project devoted to design, develop and test an innovative airborne interferometric SAR sensor. The Consortium for Research on Advanced Remote Sensing Systems (CO.RI.S.T.A.), a non profit research organization formed by three University of Southern Italy (Napoli and Bari) and two main Italian aerospace industries (Alenia Spazio and Laben), is responsible of the whole definition and development of the radar. The other partner of the initiative, consortium Technapoli, is in charge of the activities for developing applicative software that complete the research project.

Currently the system is under integration and its validation flights are scheduled in winter 04-05.

MiniSAR will be tested with respect two main applications: production of technical topographic maps and monitoring of landslide evolution, including assessment of their extension and risk area.

Particular efforts have been devoted to limit dimension and weight to allow installation on board of a small airplane (ultra-light family) but without sacrifice performance. In addition some design choices have been preferred (digital chirp synthesis, stepped-frequency) in order to make the system as flexible and expandable as possible. In fact, this is considered the first prototype for a further miniaturization of the sensor to allow its installation on board of unmanned platforms, need pointed out also by other investigators [10].

Finally, this will be the first operative airborne SAR system totally defined, developed and operated by an Italian team.

2 System parameters

Tables 1 and 2 report the main MiniSAR system parameters. They have been computed by means of a dedicated software tool, which, through graphical interfaces, includes a set of classical equations that relate the main SAR parameters [11,12]. It performs trade-offs among them and evaluates their impact on expected performance.

Typically, starting from the required resolution along range and azimuth imposed by the application and antenna characteristics, the software tool is able to evaluate the impact of each parameter, such as the transmitted bandwidth and power, pulse duration and repetition frequency on system performance, basically achievable swath, signal to noise ratio (SNR) and signal to ambiguity ratio.

It is worth noting that two main operative modes are foreseen, narrow and wide since they differ in the achievable swath, accomplished by means of two operative altitudes (3000 and 5000 meters). In order to maintain the same SNR level, different pulse lengths are implemented (18 and 30 µsec) while the transmitted peak power is left unchanged to a very low value (80 W).

	Narrow	Wide
Operative frequency	X-band, 9.65 GHz	
Polarization	Linear HH	
Transmitted bandwidth	4 x 70 MHz	
Sampling frequency	300 MHz	
Nominal aircraft velocity	70 m/s	100 m/s
PRF	210 Hz	300 Hz
Nominal off-nadir angle	45°	
Antenna elevation angle (3dB)	22°	
Antenna azimuth angle (3 dB)	2.2°	
Nominal altitude	3000 m	5000 m
Nominal slant swath	3600-5365 m	6100-8900 m
Ground Swath dimension	2200 m	3900m

Table 1 – MiniSAR system parameters.

	Narrow	Wide
Baseline length	1.5 m (physical 75 cm)	
Transmitted power	80 W	
Pulse duration	18 µs	30 µs
Range resolution (1 Look)	0.85 m	
Azimuth resolution (1 Look)	0.5 m	
Nominal interferometric resolution (slant rg x azimuth)	0.85m x 1.5m (3 Looks)	2.5m x 3m (18 Looks)
Signal to noise ratio	≥ 10 dB	
Ambiguity Signal Ratio (ASR)	< -20 dB	
Signal dynamic	20 dB	
Number of bit per sample	8 bits	
Data Rate	≤ 50 Mb/s	≤ 118 Mb/s
Data Storage (10 Km strip)	7.3 Gb	12.2 Gb

Table 2 – MiniSAR system parameters (cont.).

As far as the expected interferometric performance are concerned, it is worth noting that the accuracy in evaluating terrain height is mainly a function of baseline components, attitude angles, slant range, platform altitude and interferometric phase difference. Therefore, by supposing independent error causes, each previously mentioned parameter contributes to the total height uncertainty with its variance multiplied by the derivative of height with respect the considered parameter.

For extended target, main role is played by the variance of phase difference that, by exploiting the Cramer-Rao bound, can be expressed as a function of the number of coherent looks and image coherence, which depends on image SNR [13-15].

The resulting height uncertainties have been computed as a function of the off-nadir angle for both operative modes and evaluated for point and extended targets. They have been obtained by considering the system parameter of tables 1 and 2 and a SNR of 10 dB for extended target and 15 dB for point target and an uncertainty of 1 mm in the knowledge of each baseline component. In narrow mode a maximum uncertainty of 5 m is achievable, while in wide mode additional about 2 m are loosen. In both cases the reached height uncertainty is compatible with the production of standard topographic map, 1:25000 scaled, that is the main application of the present research project.

Since the baseline of 1.5 m gives some problems with the small aircraft where this system has to be installed on, a transmitting ping-pong mode has been implemented. In this case each antenna transmits and receives a pulse alternatively, like done in satellite multi-pass interferometry. This is equivalent to have the same performance with half the baseline, which can be easily accomplished by using ultra-light aircraft.

Another peculiar characteristic of this system is that the transmitted bandwidth of 280 MHz is achieved by 4 chirp signals of 70 MHz of bandwidth each, that are generated consecutively and translated in X band by means of 4 slightly different frequency values. Therefore, more precisely, the system works as a stepped-chirp radar. This is done for two main reasons: on one hand this working mode adds flexibility to the system that can be easily upgraded to transmit wider bandwidth, on the other hand this allows the use of more precise chirp generator devices able to assure high degree of phase linearity. This advantages are partially compensated by stronger requirements on timing system that should assure an high degree of accuracy (on the order of 1 ns) on the starting time of each transmitted chirp. Taking into account also the ping-pong mode, totally 8 chirp signals have to be transmitted each pulse repetition interval (PRI).

Regarding the hardware configuration, the system has been designed in modular boxes, so that it can be embarked on different, small aircraft.

The antennas have been designed by the University of Calabria, Department of Electronic, Information and System in Cosenza (Italy) and their prototype is reported if figure 3. The configuration is based on an multi-layer uniform array of 32x3 elements.

The antenna interface (I/F) sub-system is constituted by WR90 guidelines, circulator and ferrite switches for implementing ping-pong transmission mode.

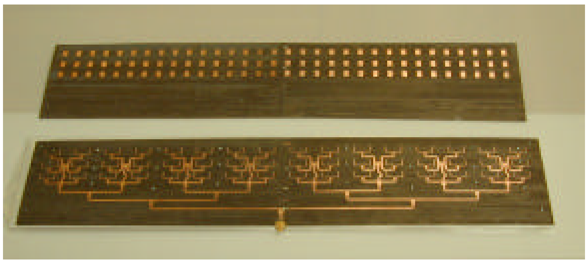

Fig. 3 – MiniSAR antenna prototype

The chirp signals to be transmitted are digitally generated by the Chirp Generation Unit (CGU). This is based on AD9852 component, a highly integrated synthesizer that uses advanced Direct Digital Synthesis (DDS) technology, coupled with an internal high-speed, high-performance (12 bit) Digital-to Analog Converter (DAC). This component allows the generation of chirp signal with bandwidth up to 150 MHz. It is mounted on board of a card provided directly by ANALOG company and it will be controlled by an additional card realized by CO.RI.S.T.A. based on PIC microcontrollers.
The Frequency Generator Unit (FGU) is the heart of the system since it is the main source of phase noise that mainly affects the interferometric performance of the radar. It provides the frequencies for the digital sub-systems and, mainly, those needed for the up and down conversion of chirp signal. Since the stepped frequency mode of the system, the FGU unit should be able to switch among four frequency values each PRI. A commercial frequency synthesizer company will be used.
The Up-Conversion (UPC) and Down-Conversion (DWC) units are responsible for up and down translation of the chirp signal before transmission and after reception in addition to accomplish the needed amplification and filtering. These two units have been realized by using COTS (Commercial Off-The-Shelf) components.
The TX sub-system is constituted by a commercial mini TWT that amplifies up to 120 W the X-band signal before transmitting it to the antenna. It is a commercial instrument in a 19’’ rack configuration. As mentioned before, the low level of transmitted power is one of the peculiar characteristic of the system.
MINISAR will be equipped with a dedicated Inertial Navigation System (INS), with an integrated GPS (Global Positioning System) receiver, in order to measure with high degree of accuracy the attitude and position of the sensor. Data provided by this sensor will be used for correcting and geo-referencing applicative products and for studying additional techniques for compensating motion errors in SAR interferometric images.
Furthermore, MINISAR will be totally autonomous from the point of view of power supply since it will be equipped with a series of battery that will assure about half hour of full operation.
To summarize, tables 3-5 report main characteristics of MiniSAR equipments, both to be installed inside the aircraft and the external ones.
Finally, from the software point of view, a complete interferometric SAR processing chain has been developed at CO.RI.S.T.A. starting from raw data to the production of Digital Elevation Model (DEM). The processing software has been tested by using airborne data from previous campaigns performed with different sensor [4]. In particular, for image compression a chirp scaling approach has been preferred [16], due to its phase preserving properties obtained without data interpolation.
To compensate motion errors the Phase Gradient Autofocus (PGA) algorithm has been implemented [17], while further improvement are expected by using also data coming from the dedicated navigation system of MINISAR.
Different methods for unwrapping the interferometric phase difference have been implemented [18,19].

Internal equipments	
Total volume	<150 Lt
Total mass	<100 Kg
Length (max extension)	966 mm
Height (max extension)	744 mm
Depth (max extension)	283 mm
Power (independent from aircraft power systems)	< 1.2 KW 24-32 V 40 A cc
Required interfaces with other aircraft systems	None
SAR operator	Not required (fully autonomous operation, only switch on-off command required to the pilot)

Table 3 – Main overall characteristics of MiniSAR equipments to be installed internally to the aircraft

3 Literature

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Subsystem	Volume (mmxmmxmm)	Mass (kg)	Power (W)
RF conversion unit	481x150x283	2	5
Data processing & AD	481x221x580	12	200
Frequency generation unit	481x139x639	25	320
TWT power amplifier	481x127x690	40	900
Antenna front-end	60x48x60	12	N/A
INS unit	175x175x248	12	14
Battery	481x127x680	*	N/A

Table 4 – Volume, mass and power budget of MiniSAR subsystems embarked inside the aircraft (* 28 lbs/battery 24V 10 Ah, for 15 min autonomy).

External equipments	
Antennae	2
Technology	Patch, multilayer uniform array
Shape	Rectangular
Depth	20 mm
Length	700 mm
Height	70 mm
Mass	<10 Kg
Physical Baseline	<75 cm
Radome	Included in antenna structure

Table 5 – Main characteristics of MiniSAR equipments to be installed externally to the aircraft

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