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SETHI / RAMSES-NG

New performances of the flexible multi-spectral airborne remote sensing research platform

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Abstract—SETHI is an airborne SAR/GMTI system developed by the French Aerospace Lab. ONERA, and integrating various sensors. In 2016 ONERA invested in upgrade and improvement of all SETHI components. The microwave ones cover from VHF-UHF to X Band, full polarimetric and very high resolution, along track and cross track interferometry and very high precision multi-baseline capacity for interferometry and tomography applications. The optronic sensors offer very high spatial resolution visible images and fine spectral scene analysis in VNIR and SWIR bands. This paper presents the upgrade and new performances of this flexible platform and the qualification campaign results with various sensor configurations.

Keywords—Remote sensing; SAR; Very High Resolution; Moving target detection and tracking; Optronic

I. INTRODUCTION

With the objective of maintaining and updating its airborne remote sensing acquisition capabilities, ONERA has been developing and up-grading its airborne remote sensing system SETHI.

SETHI is a very flexible and multi-function system used for civilian applications as forest measurements and vegetation characterization, chemical products detection and maritime survey, and defense applications as target recognition and tracking. It combines two Pods under wings which are able to carry heavy and cumbersome payloads of different kinds ranging from VHF-UHF to X band and/or optical sensors with a wide range of acquisition geometries. The Pod-based concept allows the easy integration and testing of new systems under the single certification of the Pods by authorities.

II. PLATFORM DESCRIPTION

A. The Aircraft

SETHI is onboard a Falcon 20 (Fig. 1) that is an aircraft designed by Dassault Aviation forty years ago. This aircraft (with payload onboard) can fly all over the world up-to 30000 feet, with 2.5 hours of autonomy. The ground speed can be from 200 to 400 kt.



Fig. 1. SETHI aircraft

B. Pods under wings and cabin layout

The Pod design (Fig. 2) includes an outside envelope engineered to provide transparency for electromagnetism waves in a large range of frequencies and a main beam which guarantees the necessary mechanical resistance required by the aeronautical regulations. The useful length of the Pod is 2.3 meters, its diameter is 0.535 meter and payload weight can reach 120 kg. Optical windows on the Pod nose are designed to accommodate optronic sensors.

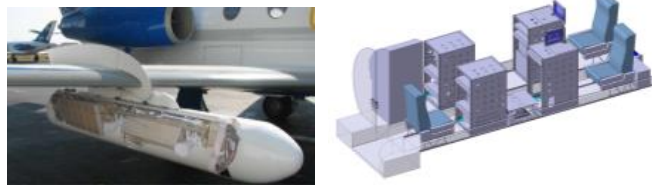


Fig. 2. SETHI Pod (with representation of inside payload) and cabin layout

SETHI new configuration cabin is composed by four 22U standard electronic cabinets and three (or four) operator seats (Fig. 2).

Overall the cabin has a total capacity of 88 U and 480 kg.

The cabin and Pod capacities allow payload boarding flexibility that justifies SETHI interest as airborne remote sensing research platforms.

III. SENSOR PERFORMANCES

SETHI flexibility is also demonstrated regarding the sensor geometry and configuration possibilities.

A. Digital core flexibility and performances

To be able to adapt the radar waveform to the scientist needs, the microwave synoptic uses an Arbitrary Waveform Generator (AWG) that generates all waveform needed (Frequential chirp, OFDM, arbitrary signal, ...) and a very high bandwidth and data-rate sampling system that is used for received signal direct sampling. This digital core is full configurable with a high level of flexibility that allows many waveform and applications.

The generation is performed by a 10 bits 2 channels 12 GS/s AWG that transmits a $s(t)$ signal pre-calculated in laboratory. We can use any arbitrary signal as Chirps, OFDM, Modulated signals, etc. and introduce notches (to avoid forbidden frequencies). The VHF/UHF, P and L Band are directly generated (no frequency up-conversion needed) with

up to 240 MHz instantaneous bandwidth. The X Band waveform is generated with an instantaneous 720 MHz bandwidth that fed an up-conversion module. The full bandwidth (4 GHz) is obtained by step frequency waveform (6 radar recurrences). AWG Multi Channel capacity is used for simultaneous multi-frequency acquisition on a same area.

The sampling system is a 12 bits 4 channels 2 GHz analog bandwidth one. Each channel is sampled at 1 GS/s I/Q data rate and the storage total capacity is 7 TB at 3.2 GB/s. These high dynamic and high data rate performances are useful for large area observation (large swath) and simultaneous multi-band area imaging. As for generation, VHF/UHF, P and L Band signals are directly sampled (no down-conversion needed), X Band signals are down-converted before sampling. Each sampling system channel is able to record several sampling windows. Multi-sampling windows is useful for system calibration, transmit signal and noise characterization.

First sampling window is used to record a copy of the transmitted signal taken just before antenna and injected in receiver input. This signal has traveled all the radar channels (Tx and Rx) and is used to calibrate the radar (expected antenna). Second sampling window is placed between transmitted signal and first received echoes. It is composed of received and radar noises and is used to measure the sensor noise (Noise Equivalent Sigma Zero estimation). The third window is the useful swath to be imaged.



Fig. 3. Multi-sampling window principle

The sampling system is equipped with a 10 Gb/s optic fiber data link that fed sampled data to a powerful hybrid CPU/GPU processor. This processor is used onboard SETHI to produce images and products of any SETHI sensor, waveform, geometry. Fig. 4 is an example of high resolution X-Band change detection obtained onboard SETHI a few minutes after second acquisition.



Fig. 4. On-board High Resolution X-Band change detection application

B. Sensor flexibility and performances

SETHI Pods carry microwave and optronic sensors covering from VHF to X Band (Fig. 4) and from 0.4 to 2.5 μm wavelength (Fig. 5).

	Radar	P	L	X	X-UHR
Center Frequency (MHz)	340	1300	9500	9500	
Bandwidth (MHz)	240 (70%)	200 (15%)	1500 (16%)	4000 (42%)	
Best resolution (cm)	62	75	10	4	

Polarisation	Full (HV)	Full (HV)	Full (HV)	Dual (HV)
Transmit Peak Power (W)	500	360	200	8000
Antenna	Dipoles	Patch array	Horns	Parabolic
Elevation aperture	100°	30°	14°	7°
Azimuth aperture	50°	10°	14°	5°
Nb. of channels	1	4	4	2

Fig. 5. SETHI radar performances

Sensor flexibilities are achieved by waveform and sensor configurations. The full bandwidth, polarimetric capacity and sensor simultaneity can be used or not, depending on mission needs.

Optronic	Optical	VNIR	SWIR
Wavelength (μm)	0.4 – 0.9 39 M	0.4 - 1	1 – 2.5
Nb. pixels	7300 columns 5400 lines	1600	320
Nb. spectral Bands		160	256
Nb. bits	16	12	14
Resolution (m) (@ range)	0.17 (@ 2.7km)	1 x 2 (@ 2.7 km)	2 (@ 2.7 km)
Geometry	Nadir or Radar LOS	Nadir	Nadir
Swath (m) (Field of view)	1300 x 950 (27° x 20°)	1600 (@ 2.7 km) (34°)	700 (@ 2.7 km) (14°)

Fig. 6. SETHI optronic performances

C. Geometry and trajectory possibilities

The Pod conception allows many sensor configurations as Along Track Interferometry (ATI), or Pod to Pod Cross Track Interferometry (XTI), and various sensors integration (optronic, radar, AIS receiver, GPS receiver, datalink ...). All these possibilities offer a large configuration panel (Fig. 7) that covers many remote sensing applications.

L Band + X Band + Optical	
VHF/UHF (P) Band + VNIR + SWIR	
X-UHR Band	
X-UHR 4 channels ATI Band	

Fig. 7. In-Pod payload configuration examples

Each Pod configuration can be plugged under any wing (Left or Right) and associated with any other Pod configuration. So we can associate VHF/UHF + VNIR + SWIR in one Pod with L + X + Optical in the other Pod for simultaneous multiband area observation; or X XTI (Tx/Rx) + Optical and X XTI+ATI for simultaneous elevation and speed measurement for example.

The radar antennas can be oriented and moved during operation. This flexibility is provided by “motorized antenna”

that can be horn, patches array, dipoles and parabolic antennas. The incidence angle of each antenna can be modified during the flight with a high accuracy (0.1 degree). This is a significant point to explore the incidence angle effect on clutter or target SER. This motorization is also used to point different radars on same area for simultaneous multi-band applications (Fig. 8). Specifically for very high resolution and long range X-UHR Band sensor, antennas are motorized on two axes, so incidence and azimuth angles can be modified during the flight with very high speed (45°/s). This is very interesting for real time aircraft motion compensation and target tracking.

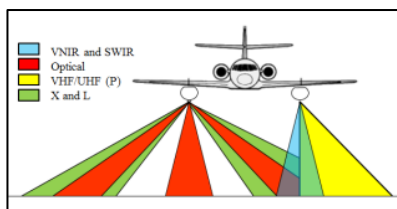


Fig. 8. Available sensors geometries

Many applications need various trajectory types (linear, circular, octagonal, etc.) to obtain target/clutter signatures on every azimuth angle for example. Other applications need very high precision trajectories for multi-pass interferometry (time coherence analysis, PolInSAR studies, etc.) or repetitive trajectory for time coherence analysis or satellite simulation. To achieve these objectives, SETHI missions are planned by an ONERA made mission planning software that allows all trajectory types, and a very high precision onboard trajectory system is used as high precision piloting assistance. This trajectory system is composed by a very high precision FOG (Fiber Optic Gyroscope) inertial sensor with 0.0025° pitch and roll measurement precision (0.005° yaw precision) and 0.6 m RMS real time position measurement (0.1 cm RMS after post processing). Pilots and sensor operators have in real time information of airborne position and difference between it and the theoretical one on compact touch-screens (Fig. 9). This view can be used for linear and circular trajectory types.



Fig. 9. Operator (a) and Pilot (b) real time trajectory display

IV. APPLICATIONS

Previous chapters demonstrated the SETHI flexibility concerning payload types, integration, configuration, geometry and trajectory. This flexibility has been used in many experimental campaigns to reach various civilian and defense objectives.

A. Forest measurement and ground characterization

Fig. 10 is an example of multi-sensors observation application, dedicated to ground characterization. It is Porquerolles island (France, Mediterranean Sea) observation with full polarization X- and VHF/UHF-Band and dual polarization L-Band SAR images, associated to very high resolution optical and hyperspectral imagery.

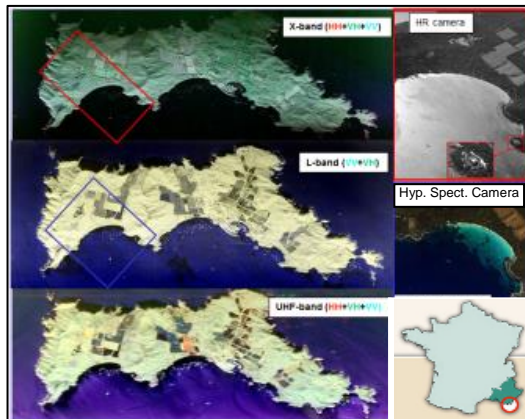


Fig. 10. Multi-sensor (X, L, VHF/UHF, VNIR and Optical) results

B. Maritime surveillance

With objective of maritime opportunity target imagery, AIS receiver has been added with antenna in Pod and receiver in cabin. This system gives GPS point of targets and the trajectory system flexibility is used to create in real time the associated trajectory (Fig. 11). With this principle have been acquired Optical, SAR and vertical profile [2].

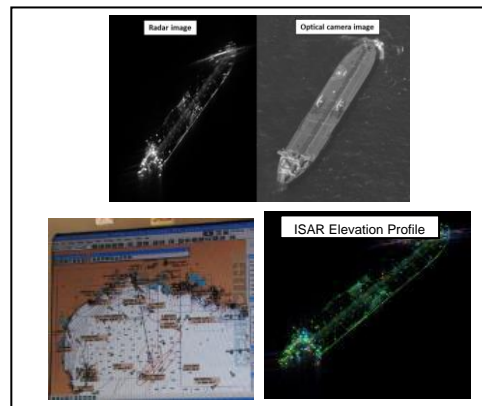


Fig. 11. Very high resolution Optical and SAR boat imagery (up) and real time onboard AIS informations and ISAR elevation profile (down)

C. Chemical product detection and characterization

Two campaigns have been realized with SETHI system with offshore pollutant detection and characterization objective. First one, called POLLUPROOF, took place in Mediterranean Sea in May 2015. The pollutants released were non-hydrocarbon one. Example presented below (Fig. 12) is SAR imagery of FAME (Fatty Acid Methyl Esters) pollutant (left part of the slick) and rapeseed oil after (right part of the slick). This example demonstrates the interest of multi-band radar for pollutant detection and characterization (various informations from different sensors).



Fig. 12. L (left) and X (right) Band full polarization SAR image of non-hydrocarbon pollutants

Second one, called NOFO, took place off the coast of Norway in June 2015. The released products were hydrocarbons, detected with Hyperspectral VNIR imagery (Fig. 13) and simultaneous X and L Band imagery.



Fig. 13. Oil slick Hyperspectral VNIR imagery

That experimental campaign has been successful thanks to the multi-sensor SETHI capacities.

D. Very High Resolution SAR imagery

The X-UHR sensor high performances are very interesting for target recognition. With 4 GHz bandwidth, the imagery resolution attains 5 cm. Fig. 14 is a zoom on a centimeter resolution (< 10 cm) circular SAR imagery on which is a lying man holding a sledgehammer, and hand tools placed on ground to write "ONERA".



Fig. 14. Zoom on Ultra High Resolution circular imagery (< 10 cm) with Human and tool detection

This Very High Resolution sensor has 2 axis real time motorized antenna that allow Spot Light mode and aircraft motion compensation. It also has a long range capacity with 8 kW transmit peak power. With long range and real time motion compensation, long range imagery can be obtained as presented on this long range (60 km) wide swath (18 km), 20 cm resolution image (Fig. 15) [3].

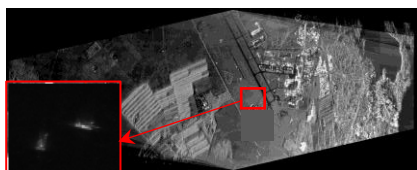


Fig. 15. Long range (60 km) wide swath (18 km) 20 cm resolution X Band imagery

Target recognition can also be obtained by using circle trajectory around the target (Fig. 16) as realized in the MULTIGIS campaign in 2013.

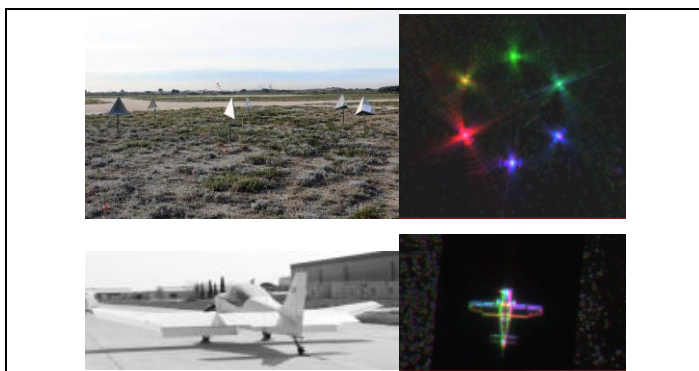


Fig. 16. X band Very High Resolution circular imagery of trihedrals and Abeille aircraft (one color per azimuth direction)

E. Ground Mobile Target Detection

The X-UHR reception antenna has many configurations: it can be a polarimetric one, a bi-source one or a 4 channels array antenna. Bi-source configuration has already been used for ground mobile target detection during DELOCCIMOSSAR campaign in 2014 [4] and ground mobile targets tracking is presented Fig. 17. Data of first airborne tests with the 4 channels array antenna are under processing.

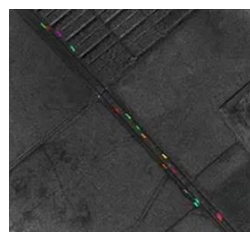


Fig. 17. X band ground target detection and tracking

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