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SAR-LIGHT, A VERSATILE SAR SENSOR ON UAV PLATFORM FOR TARGET CHARACTERIZATION

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ABSTRACT

ONERA, the French aerospace lab, has been developing over the past two years SAR-Light, a drone-embedded SAR tool. Our aim is to achieve equivalent performances to those of SETHI, ONERA's plane embedded SAR tool [1], while enabling more flexible acquisitions. SAR-Light is now able to reach an 0.08 meter resolution (in X-band) without the need for autofocus, and has proven capable of performing advanced SAR modes, both in X- and C-band, and in full-polar. Here we display milestones of the development of SAR-Light, along with a few of its recent achievements during flight test campaigns, and more operational use cases.

Index Terms— SAR, drone, UAV, imaging, radar

1. INTRODUCTION

ONERA's SAR sensors have been under constant evolution. It started with RAMSES [2], carried on a Transall C-160, and a STEMME (BUSARD [3]), to SETHI on a Falcon-20 [1]. The miniaturisation of remote sensing sensor has enabled the use of UAV platforms. Namely, UAV have drawn interest of the SAR community as sensor carriers [4, 5, 6, 7, 8]. Thus the lab is now getting enriched by a drone-embedded SAR measurement tool, which enables a larger set of trajectories. With this UAV we aim to reach the same image quality as with previous sensors. However the limited 6kg payload puts high constraints on the hardware development.

2. DEVELOPMENTS

2.1. Hardware

SAR-Light is embedded on a commercial DJI-M600 UAV. The system development is based on a modular strategy using PXIe digital cards, X-microwave modules, custom patch transmit and receive antenna and compact inertial unit. Addition of components like multipliers, filters and amplifiers allow one to adapt the radar chain to the required frequency band and geometry while respecting the strong constraints of weight and size. An on-board CPU controls the whole system. The radar part operates in LFM CW (Linear-Frequency

Modulated Continuous Waves). The whole system is packed within a 3D-printed structure as displayed on figure 1. The currently operational configurations are presented in table 2.1.



Fig. 1. The SAR tool embedded under the UAV. The structures holding the RF parts and the antennae are 3D printed. The antenna needs to be oriented manually.

Parameter	X-band	C-band
Central frequency	10GHz	5.275GHz
Bandwidth	1800MHz	750MHz
Sampling Frequency	10-20MHz	
Beamwidth	22°x22°	
Incidence angles	15°, 30°, 45°, 60° & 75°	

2.2. Trajectory reconstruction

Trajectory reconstruction has always been a key element in SAR imaging. Namely a subwavelength knowledge of the trajectory is required to reach satisfying focalisation, and SAR-Light typically operates in X-band (10GHz), id est 0.03m wavelength. The limited payload however superimposes the tradeoff with the IMU (Inertial Movement Unit) accuracy. The chosen solution for SAR-Light is based on

specific category of MEMS technology developed by SBG System. The actual 3D position of the UAV is then further refined by post-processing and the use of a dense-network of GNSS stations, as to correct GNSS errors [9]. Eventually since the UAV trajectories are typically very short with respect to the GNSS network, it requires the addition of ground stations close enough to the measurement area.

3. CAMPAIGNS

3.1. Validation

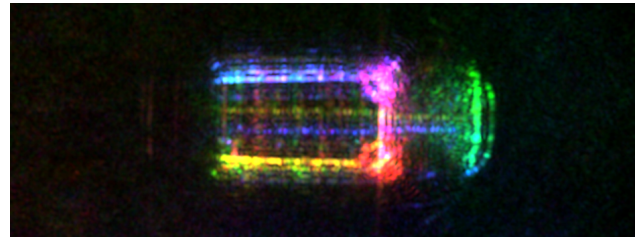
The first experimental acquisition campaign with the SAR-Light instrument was carried out in April 2021, in the South of France. As already presented in previous papers [10], SAR data were collected in X-band, the main objective being to assess the performances of the SAR-Light instrument. The spatial resolution was at the time 0.25 m (600 MHz bandwidth) and images are processed with an azimuth (alongtrack) resolution equal to the range resolution (across-track). To evaluate the SAR image quality, seven trihedrals were deployed and geolocated with an accuracy of few centimeters. An EM absorber area (2.4m x 2.4m) was also installed to estimate the instrument noise level. Over 60 SAR-Light images in 2.5 days were acquired during this flight test campaign. These measurements involved range and azimuth geolocation accuracy evaluation, radiometric accuracy measurements from trihedrals RCS, instrument noise measurements. Imaging of a building complex was performed as well, using a linear flight trajectory.

3.2. Characterization

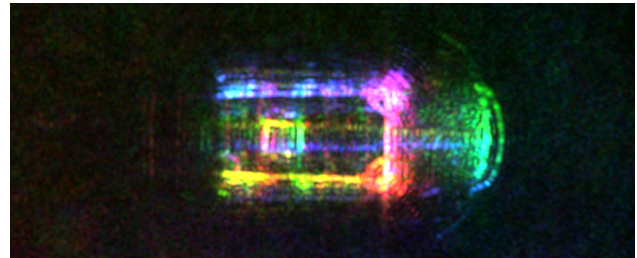
The campaign carried in June 2022 aimed to perform more situational configurations. SAR-Light is now operated in four polarizations, both in X- and C-band, with incidence angles ranging from 15 to 75° with 15° steps. The measurements were carried both on an airfield, which was mostly flat with a small building, and on a more hilly and vegetated area, with flight altitudes of 5, 10, 50, 85 and 120m. These measurements implied among others several circular trajectories around vehicles at several flight altitudes and incidence angles, as to fully characterize their radar signature. This paper presents only a few results of the 97 measurements performed over 5 days.

Figure 2 displays an example of target signature measurement. Here the drone would perform circles around a truck at 50m height with a 45° incidence angle, while pointing at the truck. Images were then calculated for 10° integration angle, thereby reaching a 0.08m resolution, and added on top of the others. Images in figure 2 consist of 360 images measured at different angles, and the illumination direction is encoded in RGB colors. The truck was imaged both with and without a metallic box, so as to evaluate change detection performances.

A similar configuration is displayed in figure 4 for imaging a more complex scene, involving people and various objects, so as to evaluate SAR-Light's potential on more operational scenarios. Additionally the 1800MHz bandwidth in X-band enables a 0.08m range resolution, and we could reach the same resolution alongtrack without the need for autofocus.



(a) Empty truck



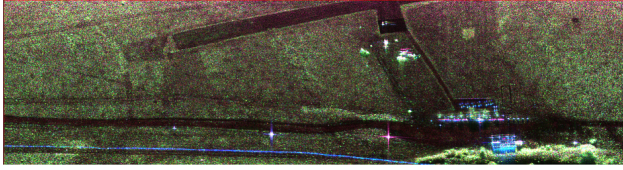
(b) Loaded truck



(c) Optical view

Fig. 2. Concatenation of SAR images measured while the drone was performing a circle around the truck. Each color corresponds to a different illumination direction. On image (b) the truck was loaded with a metallic box. Red corresponds roughly to an illumination from the top left of the image, green from the top right and blue from the bottom. The radar was in X-band with 45° incidence. 360 images were used, each is integrated over 10°

The result displayed in figure 3 demonstrates the ability of SAR-Light to perform measurements on a larger operation field, with the advantage of being fast to operate. The result is a combination of 3 images with different polarizations measured simultaneously in stripmap mode in C-band. The polarization enables to visualise man-made structures, such as the wire fence at the bottom.



(a) Polar SAR image



(b) Google Earth view

Fig. 3. Summation of Hh, Vv and cross-polarization SAR images of the testing area in C-band in stripmap configuration. Red is for Vv, green is for cross polarization and blue is for Hh. The base camp from figure 4 is visible at the center of the SAR image. The wire barrier at the bottom of the image is visible in blue, along with other man-made constructions. The three bright points along the barrier are corner reflectors.

4. FUTURE DEVELOPPEMENTS

Future developments involve the addition of lower frequencies, automated drone displacements, a more accurate IMU, in-flight command of the viewing angle.

5. CONCLUSIONS

SAR-Light is now a fully operational X- and C-band full polarized SAR sensor able to collect data with a spatial resolution down to 0.08m and covering a swath of 80m to 170m (in slant range geometry). As reported in this paper, a several flight test campaigns have enabled the acquisition of experimental SAR data for the validation of the instrument's performances. Moreover there are still further developments in perspective such as the addition of UHF-band, while improving the robustness and stability of the system.

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Fig. 4. Concatenation of SAR images measured while the drone was performing a circle around the scenery. Each color corresponds to a different illumination direction. One can identify on top of the image the car visible at the back of the photo, as well as the four poles of the tent in the center and the sleeping man at the left-hand-side. Red comes roughly from the top left, green from the top right and blue from the bottom of the image.