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# LATEST UPGRADES ON SAR-LIGHT, ONERA'S UAV-EMBEDDED SAR TOOL

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**Abstract**—ONERA, the French aerospace lab, has been developing a drone-embedded SAR imaging tool, SAR-Light. Now that it has been fully characterized in both X- and C-band and in full polarimetry, and demonstrated to reach similar imaging capabilities as larger carriers despite a 6kg payload, we focus on more operational use cases. In this paper we display recent results for target characterization and scenery inspection, which demonstrate the high repeatability of image projection from one flight path to another. The limited payload however puts high constraints on the inertial measurement unit, although trajectory reconstruction is critical for synthetic aperture radars. In this work we demonstrate the high reproductibility of our results by characterising non coherent change detection at short range with very diverse objects. We introduce a recent demonstration the latest upgrade of our system with a new inertial measurement unit.

**Index Terms**—SAR, UAV, remote sensing, change detection, drone

## I. INTRODUCTION

UAVs (Unmanned Air Vehicles) have driven major interest over the past few years as they became extensively commercially available at low costs. This interest has spread to the SAR imaging community in general [1], [2], and to ONERA, the French aerospace lab, in particular. Namely they offer a versatile, low-cost, easy-to-deploy carrier for SAR sensors. Typical applications found in the litterature involve SAR imaging [3], [4], sub-surface detection [5], [6], InSAR [7], [8]. However this comes at the cost of a smaller payload, what may put high constraints on the performances. Thanks to the miniaturization of remote sensing electronics, it is now possible to embark a SAR tool on a UAV platform, yet it remains challenging. ONERA has gained a strong experience in SAR imaging over the past decades thanks to its home-developed sensors on larger carriers. It went from RAMSES [9], carried on a Transall C-160, to BUSARD [10], carried on a STEMME, and SETHI [11] on a Falcon-20. While developing SAR-Light, our drone-embedded SAR imaging tool, we would aim at reaching the performances we display on larger

carriers. These were detailed in a previous publication [12], which was mostly system-oriented, with a focus on trajectory reconstruction and image qualification. In this publication we display a few use cases of target characterization in a complex environment, and scene inspection. These use-cases rely on the reproductibility of the images from one flight path to the other. While the change detection scenario was performed with a SBG Systems MEMS inertial measurement unit IMU), the large scenery inspection scenario was imaged with a recently-installed INSD IMU from Inertial Labs.

## II. SYSTEM DESCRIPTION

SAR-Light is embedded on a commercial DJI-M600 UAV, with 6kg payload. The system is home-designed, using PXIe digital boards, X-microwave modules, custom patch transmit and receive antennae. The radar part can operate either in Xband (10GHz) and C-band (5.275GHz) in FMCW (Frequency Modulated Continuous Waves). The trajectory is estimated by combining the data of both a compact inertial unit and GNSS data, extra ground-based GNSS stations and PPK (Post Processing Kinetics), what allows us to reach a 0.08m image resolution along-track and cross-track in X-band, and 0.15 cm in C-band. We insist on the fact that those are intrinsic performances, without the need for autofocus. This requirement implies a sub wavelength trajectory reconstruction. Major characteristics are reported in table I. The drone is displayed along with its payload in figure II.

TABLE I  
SAR-LIGHT CHARACTERISTICS

Parameter	X-band	C-band
Central frequency	10GHz	5.275GHz
Bandwidth	1800MHz	750MHz
Beamwidth	25°x24°	38°x38°
Azimuth resolution	up to 0.08m	up to 0.15m
Incidence angles	15°, 30°, 45°, 60° & 75°	
Polarisation	Hh, Hv, Vh, Vv	

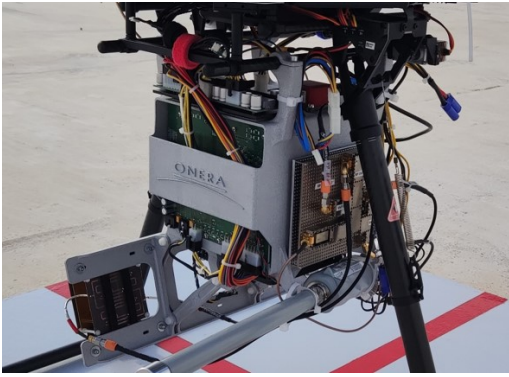


Fig. 1. SAR-Light embedded under its DJI-M600 carrier. The antennae and the 3D-printed chassis are visible.

### III. MEASUREMENTS

#### A. Close-up inspection

The scenario presented in figures 3.c and 3.d is particularly interesting since it displays an assembly of various types of targets (two vehicles, people in various positions, objects of various materials arranged 3D structures...). The two RGB images 3.a and 3.b are circular measurements of the same scenery, a minute apart from one another.

The drone was circling around the scenery while measuring, with a 10m flight altitude and 30° incidence. The images were calculated every five degrees. Each image is displayed in a specific color, and then stacked over the others to form the final RGB result. This way, each color corresponds to a different measurement direction. One may easily recognise the car at the top of each image, or the four dots corresponding to the four poles of the tent for instance.

The characters would hold still during each circle. Between two circles, characters have changed locations and positions, picked up and displaced objects, opened the vehicles' doors, unrolled a metal cable. The superposition image 2.e helps understanding the scenario. Elements which are visible only in the first image are displayed in blue, those visible on both images in light blue, and those visible in the second image only appear in green. These changes are detected automatically in figure 3.f, based on a generalized likelihood-ratio test (GLRT) as developed in [13], with a 4-pixel sliding window, local average correction and two  $\pm 0.8$  thresholds. Elements below the lowest threshold appear in blue, those above the highest ratio appear in blue, and those inbetween appear in white. The change detection raises numerous false alarms at the edges of the figure. This is because the drone is very close to the scene, and these false alarms are at the edges of the lobe.

It is remarkable enough to note that the 3D structures such as the tent, which are unchanged from one image to the other, disappear from the change detection image. In an equal way the fine details of the vehicle at the top of both the superposition and change detection images (figures 2.e) and f) are clearly visible. This is quite an achievement as this implies that both images must have the same projection, with a subpixel

error tolerance. This was made possible by calculating each image of the second circle using the projection grid of the corresponding image in the first circle. The changes detected at the location of the roof of the vehicle depict in fact the interior of the vehicle, which becomes visible, now that the doors are open.

#### B. Large scene inspection

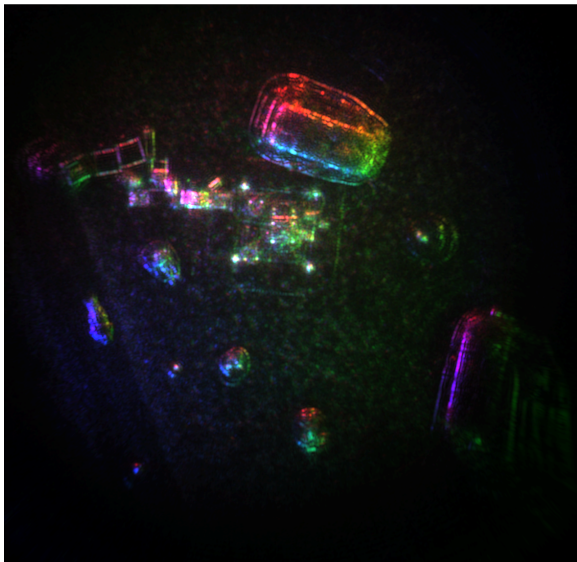
This measurement displayed in figure 3 was performed at Eyguieres airfield near Salon-de-Provence, France, at 85m above-the-ground flight altitude, with 30° incidence angle, resulting in a 200m slant range swath. The ground is essentially flat, and mostly covered with dry grass and soil. The two corner reflectors used for image calibration are clearly visible. The image was calculated with a 15 centimeter resolution. We have discussed the limitations inherent to the accuracy of the IMU in the previous section. Figure 3.a) is the first demonstration of a SAR image measurement using our new IMU from Inertial Labs. The quality parameters in figure 3.c) are quite satisfactory for a first-shot measurement with strong wind conditions.

### IV. CONCLUSION AND FUTURE DEVELOPMENTS

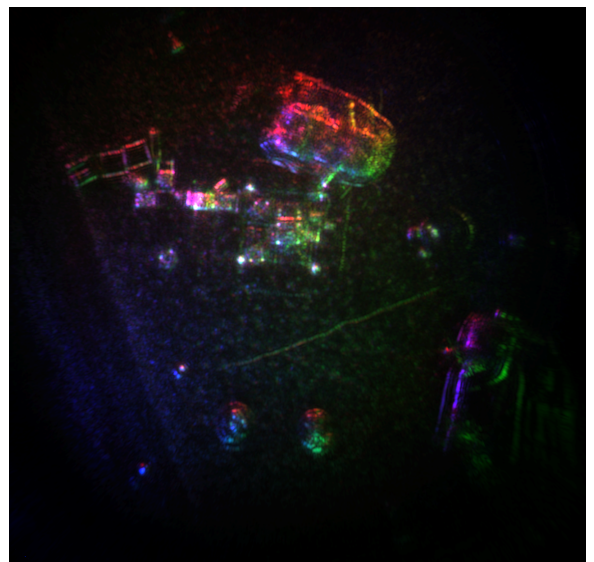
With SAR-Light we have now started capitalizing on the very large amount of data collected during the previous campaigns. We have demonstrated a real-life repetability of the measurements over the same area, despite the limitations related to the uncertainties of light-weight IMU. We are currently working on coherent change detection, to benefit of the full potential of radar imaging. This is however more challenging since it requires subwavelength co-registration of both images. While writing, we are performing further tests with a recently-developped a UHF-band acquisition chain, and the newly integrated IMU. The drone is thought of as a prototype, and is therefore intended to be under constant evolution. Envisaged features include in-flight command of the incidence angle, and flight schedule automation. The authors would like to thank all the members of the team not mentioned as authors, but who still took a great involvement in the project: Hubert Cantalloube, Sebastien Angelliaume, Jerome Henrion, Gilles Duteil, Philippe Martineau, and more particularly R'emi Baqu'e and Nicolas Pastorino for their involvement in the last measurement campaign.

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(a) Before change



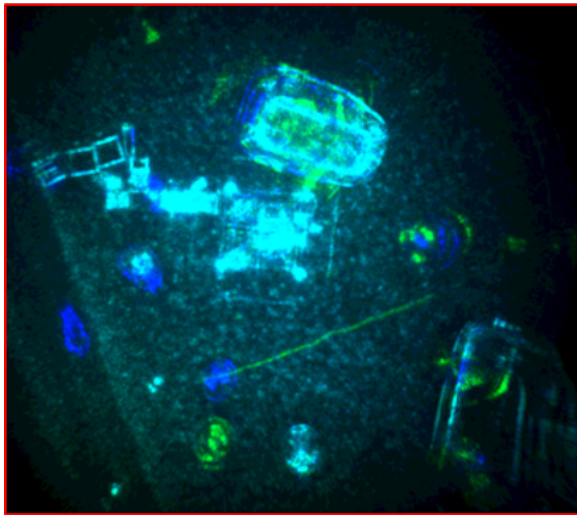
(b) After change



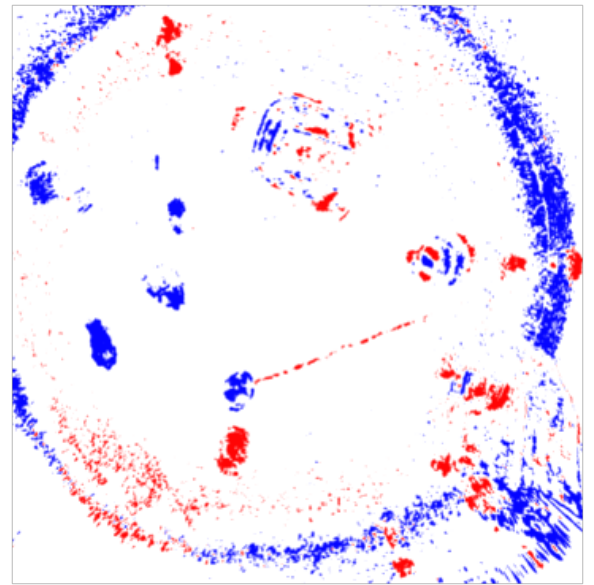
(c) Optical view of the scenery before changes



(d) Optical view of the scenery after changes

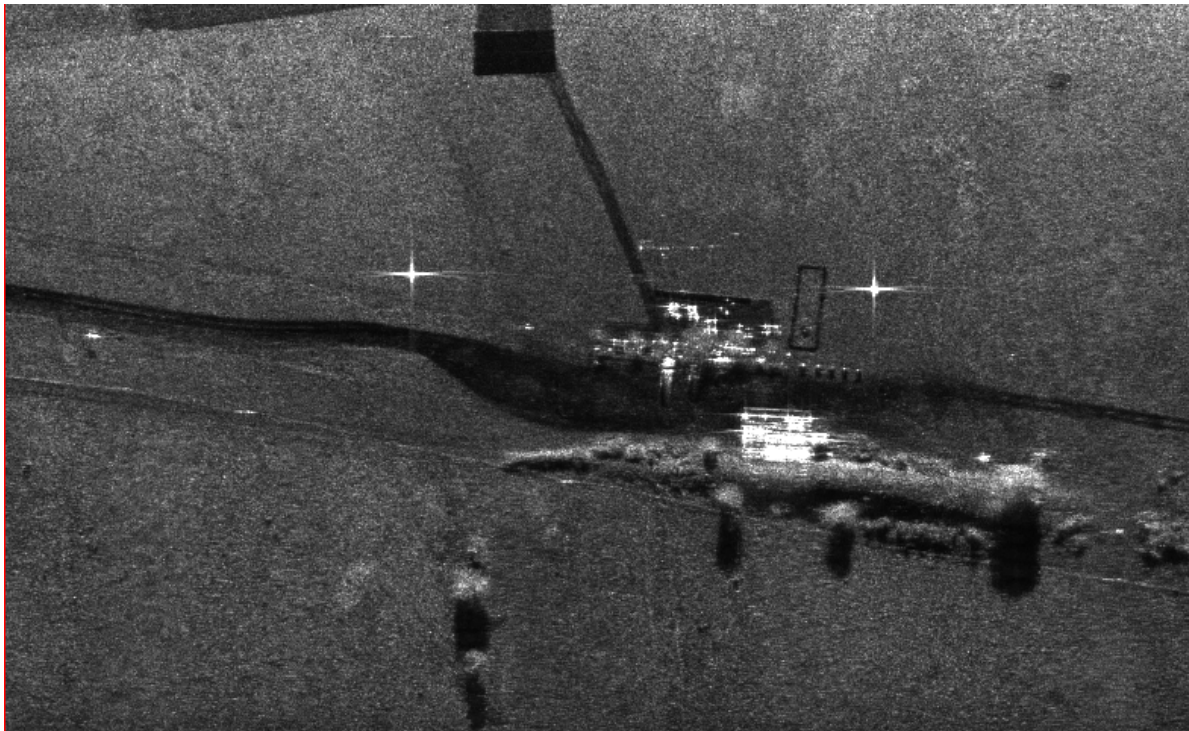


(e) Superposition of images a) (dark blue) and b) (green).



(f) 2-threshold change detection

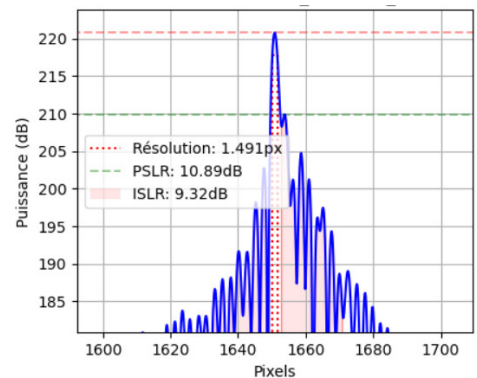
Fig. 2. (a) & (b) Concatenation of SAR images measured while the drone was performing a circle around the scene. Each color corresponds to a different illumination direction. One can identify on top of the image the car visible at the back of the photo, as well as the four poles of the tent in the center and the sleeping man at the left-hand-side. Red corresponds roughly to an illumination from the top left of the image, green from the top right and blue from the bottom. Images were calculated every  $5^\circ$ . (c) & (d) Corresponding photos. (e) Superposition of images (a), encoded in dark blue, and (b), encoded in green. Common features appear in light blue. (f) 2-thresholds non-coherent change detection, revealing objects present before (blue) and after (red) the changes occurred. It is remarkable to note that the tent, which remains still from one image to the other, is not visible on the change map.



(a) SAR image of the Eyguieres airfield



(b) Google Earth aerial view



(c) Corner reflector response

Fig. 3. (a) X-band images of the Eyguieres area using the new IMU, along with its optical equivalent (b) and a corner reflector response (c) to assess the image's quality parameters.

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