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# Early Development In Synthetic Aperture Lidar Sensing and Processing For On-Demand High Resolution Imaging

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*Abstract*— **The quest for real-time high resolution is of prime importance for surveillance applications specially in disaster management and rescue mission. Synthetic aperture radar provides meter-range resolution images in all weather conditions. Often installed on satellites the revisit time can be too long to support real-time operations on the ground.**

**Synthetic aperture lidar can be lightweight and offers centimeter-range resolution. Onboard airplane or unmanned air vehicle this technology would allow for timelier reconnaissance.**

**INO has developed a synthetic aperture radar table prototype and further used a real-time optronic processor to fulfill image generation on-demand. The early positive results using both technologies are presented in this paper.**

*Index Terms*—**Synthetic aperture lidar, synthetic aperture radar, real-time, optronic processor**

## I. Introduction

In multiple remote sensing applications there is an increasing need for information of higher quality. Though quality is somewhat a subjective notion, it often translates into high resolution imaging capabilities. The ultimate goal of remote sensing is to have more detailed knowledge to better diagnose an observation or situation. For search and rescue teams, for instance, a better understanding of the actual state of a region in the midst of a natural disaster will increase the efficiency of rescue priorities identification and of viable routes to bring help to communities in need.

Synthetic Aperture Lidar (SAL) is an emerging technology that provides active day and night imaging capabilities within a compact payload. SAL is derived from its radar counterpart Synthetic Aperture Radar (SAR). It provides a means to overcome the limitation of a small collecting aperture through synthesis over a large collecting distance. Due to its small wavelength, 4000 times smaller than SAR, SAL could offer very high resolution within a small payload.

In this perspective, INO has recently developed a tabletop prototype of a SAL imager. INO has also, in partnership with ESA, successfully developed an optronic SAR processor for the real-time generation of SAR images from the ENVISAT/ASAR instrument. This SAR, now SAL, processor, has been used to successfully process in real-time raw data from the SAL system to form a SAL image.

This strategy combines the best of two worlds. SAL sensors, due to their high pulse repetition rate, will generate very large data throughput that must be processed in real-time to make any observation/surveillance system useful. Combining a SAL head to an optronic SAL processor provides a mean to achieve, within a compact lightweight payload, high resolution imaging in a timely fashion. This paper reviews results obtained with the SAL prototype and the SAL optronic processor.

## II. Synthetic Aperture Systems

In remote sensing, conventional imagers must often sacrifice ground resolution for system compactness since in these systems the resolution is limited by the aperture size. A technique to obviate the diffraction limitation of an imaging system's real aperture is known as Synthetic Aperture (SA) and has been successfully employed at radio frequencies on both space-borne and airborne platforms for many years. These active imaging systems (Synthetic Aperture Radars or SARs) take advantage of the platform motion to coherently sample multiple sections emulating an aperture much larger than the physical one. The backscattered data returns are then coherently reconstructed to produce the final high resolution SAR image. Typical SAR systems operate at centimeter wavelengths, have antenna sizes of close to ten meters and produce images with ground resolutions less than ten meters. Synthetic Aperture Lidar (SAL) systems [6][7][8][9][10] that would operate at wavelengths one thousand times smaller than

SAR systems thus could potentially offer images with ground resolutions of tens of millimeters within a compact envelope. These kind of resolutions would provide critical and precise information for disaster management teams. In this paper the data acquired by a synthetic aperture lidar prototype are further processed with a optronic processor to demonstrate the basic elements of an on-demand high-resolution imaging system.

Typical SAR imaging systems consist of two distinct operations employing different technologies. SAR raw data acquisition, illustrated in Figure 1 is performed with a radar antenna that acts as both the transmitter and receiver. SAR image reconstruction is either digital where the raw date are run though mathematical algorithms such as Range-Doppler or Chirp-Scaling on computers or optronic (based on digital holography [1][2][3] and illustrated in Figure 2) where the raw data are coherently illuminated and lenses are inserted into the beam's path focusing the raw data to form the image that is in turn captured by a digital camera or on film.

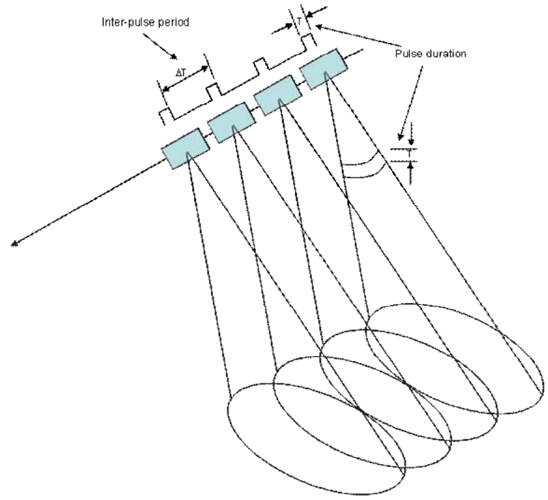


Fig. 1. Illustration of a SAR image acquisition system

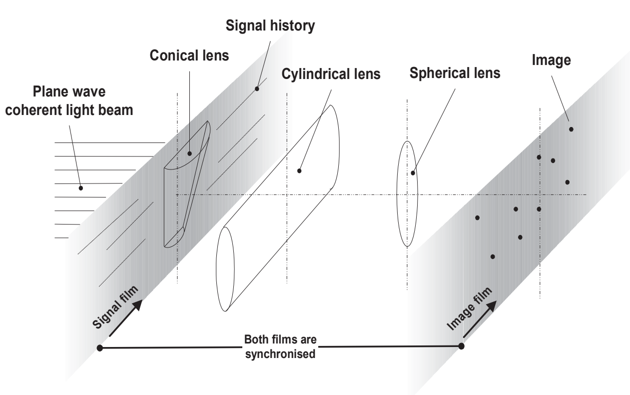


Fig. 2. Illustration of an early optronic SAR processing system

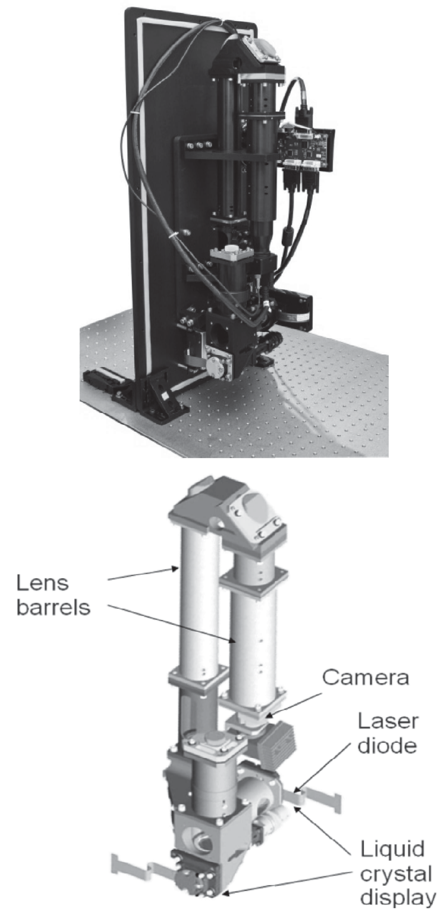


Fig. 3. Photo of the optronic processor (left) and corresponding schematic (right)

A SAL system is basically the equivalent of a SAR system where the radar wavelength is replaced with an infrared wavelength, a thousand time smaller, yielding a more compact system and eventually much higher resolution.

Figure 3 presents an image (left) and schematic drawing (right) of a prototype optronic SAR processor designed to reconstruct SAR images from specifically from ENVISAT/ASAR data [4][5]. In this implementation, the SAR raw data is fed into the system through two spatial light modulators, one for the amplitude component and one for the phase component, illuminated by a coherent laser beam. The optronic processor is composed of two main sections. A SAR relay maps the amplitude information over the phase information. Once combined, both components are propagated simultaneously into the optical system. The light propagation combined to the lenses induced modification refocused the raw data to generate a SAR image. Since the light propagation performs the generation of the image, the computation is made at the speed of light. The actual processing capabilities of the processor is defined by the refreshing rate of the SLMs, their dimensions, in this case 1920x1080 pixels, and the SAR parameters such as azimuth compression ratio and range compression ratio.

## III. Synthetic Aperture Lidar Sensing and Processing

### A. Fiber-optic SAL image acquisition system

A first laboratory SAL image acquisition system set-up was designed and built. It is illustrated in Figure 4 and shown in Figure 5. The purpose of the prototype was to verify the feasibility of the concept of sysnthetic aperture lidar. The system is based on an eye-safe tunable laser operating at 1.5 µm with an average output power of 8 mW. The pulse duration was set to 0.6sec and the pulsed bandwidth to 1 THz. The optical fiber used was a single mode SMF-28.

The laser beam is sent onto a target, tilted as in SAR systems, and the echo is captured by the same channel. The distance between the lens and the target is 30 cm. In parallel a part of the illumination beam is used for reference and is sent to a second path and reflected through the use of a corner reflector back to the source. This reference plays a role similar to a local oscillator found in SAR systems. The beam collected from the target is combined to the reference beam and the interference pattern is recorded. This becomes the raw data that will be further processed with the SAR, now SAL, optronic processor. Typically the optical length of the reference and the target paths will be balanced i.e. mostly similar.

The target, shown in the bottom section of Figure 6 was constructed by hand from reflective tape, glued on wood board and mounted on a translation stage. The translation stage was controlled by the executable Labview program. The top illustration of Figure 6 shows the size of a target compared to the size of the laser beam profile. The beam width is much larger than the target illustrating the point that using synthetic aperture techniques, features much smaller than the illumination spot-size can be resolved.

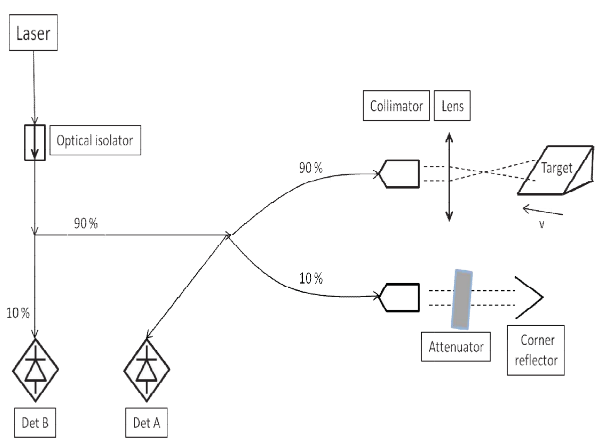

Fig. 4. Schematic of the SAL laboratory set-up

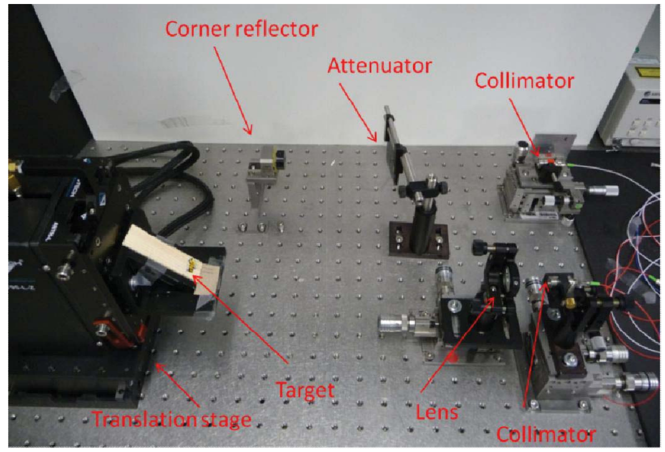

Fig. 5. Photo of the SAL laboratory set-up

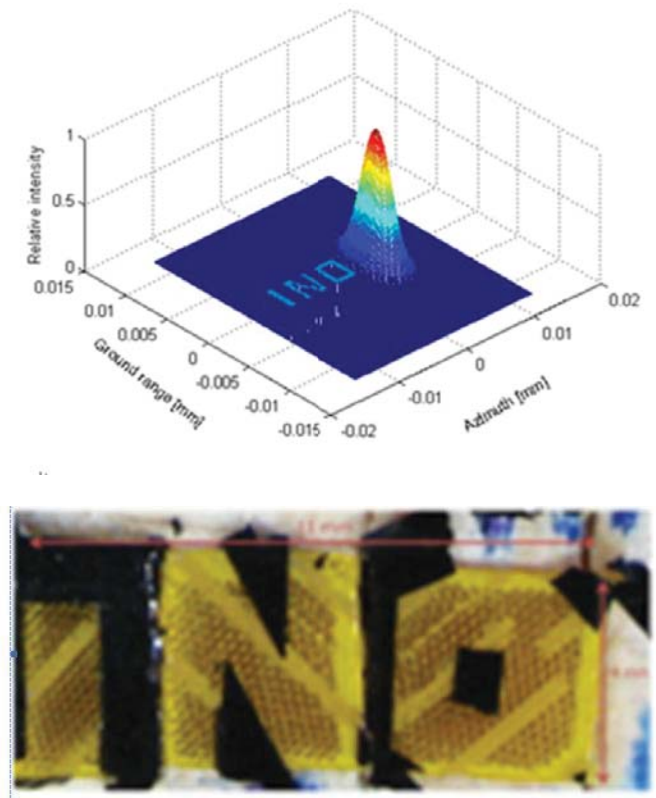

Fig. 6. Illustration of the target size as compared to the beam width (top) and photo of the target (bottom)

### B. Optronic processing of SAL data

SAL sensors will provide very high resolution but will also generate huge amounts of data. To cope with this large data generation rate, an optronic processor was used. The optronic processor exhibits real-time processing capabilities and will be a key element for any real-time applications foreseen.

The data acquired by the SAL set-up is processed using the optronic SAR processer designed for ENVISAT/ASAR data. No changes were made to the optronic processor; only a straightforward scaling was performed to change raw data focal lengths.

The SAL raw data is thus input on the SLMs, propagated to the processor, and the reconstruction is captured on the camera located at the exit of the optronic processor. Figure 7 shows a comparison between a theoretical SAL image (simulated image acquisition and processing, top) and the real processed SAL image (data taken with the fiber-based set-up and processed with the optronic processor, bottom ). The optronically processed real image shows good agreement with the theoretical image. The three letters, I, N and O are clearly seen as well as details of the rectroflective structure (diagonal lines).

It can also be observed that the diffusing black diffusing wood board is imaged. This is an excellent result since diffusing materials exhibit much lower reflective properties. This is also the very first step toward the use of SAL in a wide range of applications.. Speckle can also be observed, as expected from a coherent imaging system.

Quantitative analysis of the image further shows that the resolution obtained is better than 300 μm in range and 80 μm in azimuth which compare nicely to the theoretical values of 255 μm and 57 μm respectively.

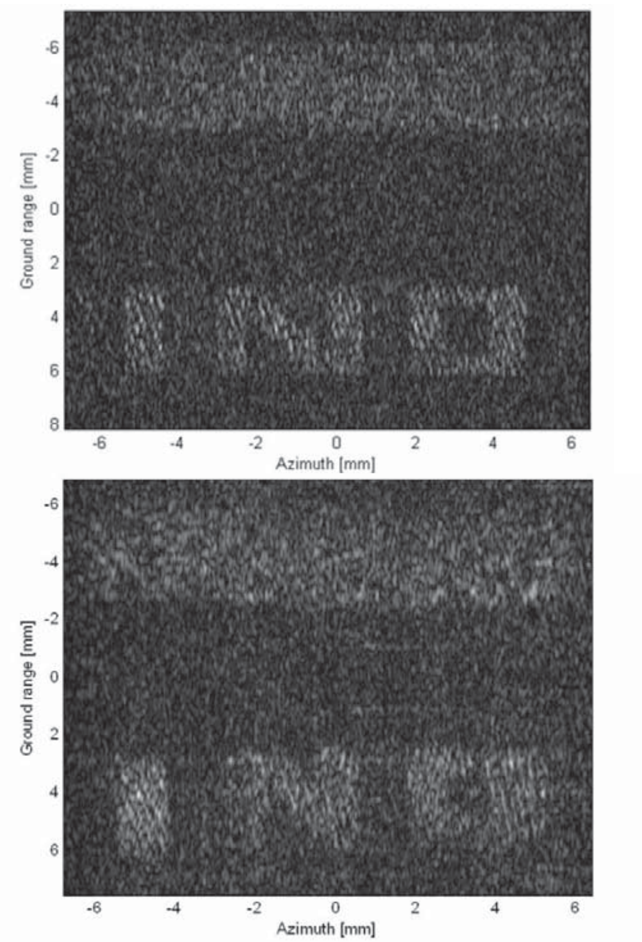


Fig. 7. Theoretical SAL image (top) and real all-optical SAL image (bottom)

## IV. Conclusions

A synthetic aperture lidar laboratory prototype was built and tested. The raw data generated by the SAL head were further processed optronically and compared with digitally processed images. The results obtained showed good agreement between the experimental and theoretical resolutions. Furthermore images were obtained from both diffusive and retro-reflective materials opening the door to a wide range of surveillance application. The optronic processor is ideally suited for the large data throughput that will be generated by future SAL sensors.

## V. Acknowledgments

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