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Lightfield LiDAR System for Lunar Landing Assistance

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ABSTRACT

This paper presents the current development of a LiDAR system based on Lightfield technology for assistance in Lunar Landing. TNO and OMMATIDIA are leading the co-development effort with the goal to adapt the unique Lightfield LiDAR technology of Ommatidia for space applications. The main specifications for this LiDAR are a field of view of 23 deg x 23 deg, within a range interval of 150-1000 m, offering more than 18000 points/s, with a full frame achieved in 5 s. In the paper the main architectural choices are presented, with a specific focus to the unique advantages of the Lightfield solution. Moreover, the current development status and plan for the near future is also presented.

Keywords: LiDAR, FMCW, Photonic Integrated Circuit, Lunar Landing

1. LIDAR SPECIFICATIONS

Under the cooperation SPACIAL (SPACe lIdAr for Landing), TNO and OMMATIDIA are codeveloping a LiDAR system for space navigation application. The main driver for this cooperation is the intention to explore the unique Lightfield technology of OMMATIDIA for space applications such navigation assistance for Lunar Landing, proximity operations, rendez-vous and investigation of space objects. After a general study of the design parameter landscape, the study has been devoted at the system design of a LiDAR system for Lunar Landing assistance.

The ranging technique for the SPACIAL LiDAR is based on Frequency Modulated Continuous Wave (FMCW), where a continuous wave laser is modulated in frequency, and the ranging information is collected by means of coherent detection on the beating signal formed by superposition of the local oscillator and the return signal. The advantage of the FMCW concept is the possibility to exploit coherent detection, with clear benefits in terms of Signal-to-Noise Ratio, the possibility to operate the laser at continuous wave, avoiding high peak power operation conditions, and the inherent capacity of FMCW system to extract Doppler velocity information. Moreover, an additional advantage of the usage of coherent detection lies in the possibility to have available the full complex information of the return signal. This characteristic is used in the Lightfield concept developed by OMMATIDIA to realize a beam-forming network in the receiving path, to be able to acquire lens-less lateral resolution. More details on the implementation of the Lightfield concept in combination with the FMCW architecture can be found in.[1] In the SPACIAL system the Lightfield concept along one dimension is combined with a precision mechanical scanning in the orthogonal direction.

The specifications of the SPACIAL system are reported in Table 1.

2. SYSTEM DESIGN

The SPACIAL LiDAR is based on a Hybrid Lightfield-Mechanical scanning architecture, which is schematically shown in Figure 1. On the Optical Scanning Plane (OSP) 1024 optical channels are collected simultaneously resorting to the beamforming network of the PIC Receiver, while illuminating the scene with a line of light matching the angular field of view of the receiver. The scene exploration on the Mechanical Scanning Plane (MSP) is performed by means of mechanical scanning.

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Table 1. SPACIAL Specifications

Range Interval	150-1000 m
Field of View	23 deg x 23 deg
Frame Rate	0.2 s
Point Rate (Long Range)	> 18000 points/s
Point Rate (Short Range)	> 150000 points/s
Lateral Resolution	2.7 mm @ 500 m (OSP) & 28.5 cm @ 500 m (MSP)
Range Resolution	0.6 mm
Single Point Accuracy	62.4 mm (3σ)
Operational Wavelength	1550 nm

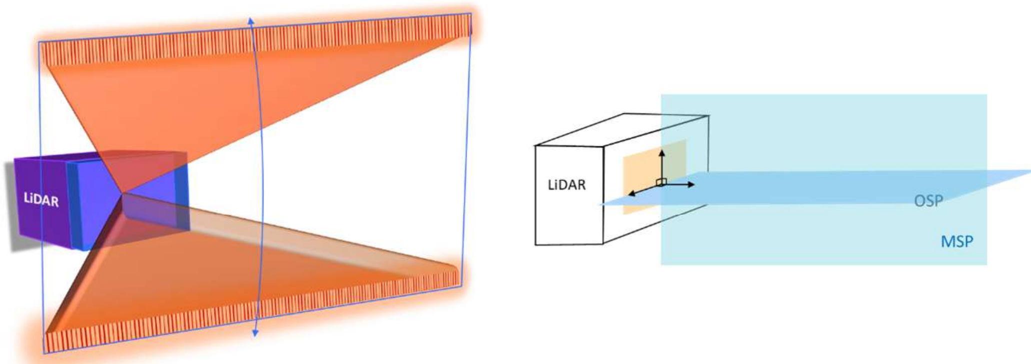

Figure 1. Sketch of the Hybrid Lightfield-Mechanical scanning architecture of the SPACIAL LiDAR: Lightfield simultaneous acquisition on the horizontal axis complemented by the mechanical scanning on the vertical direction to fill the entire scene (left); definition of the Optical Scanning Plane (OSP) and Mechanical Scanning Plane (MSP), in agreement with the architectural definition. The illumination is composed by a frequency modulated high power laser, emitted by a free-space fiber termination. The laser beam is properly conditioned in size and divergence by the transmitter optics contained in the Optomechanical System. A portion of the transmitted light is tapped and directed towards the PIC Receiver, to enable homodyne coherent detection.

2.1 PIC Receiver

The PIC Receiver is the core technology offered by OMMATIDIA. The PIC Receiver consists of an integrated Photonic Integrated Circuit, based on Silicon technology, which has already been scouted for space-based operation,[2] integrated with a Read Out Integrated Circuit (ROIC), which is devoted to readout of the integrated detectors. 1024 optical channels collecting the return radiation are mixed in phase and in quadrature with the local oscillator coming from the illumination path. The beating signal is detected by Germanium detectors, and the analog signal is read out by the ROIC. The latter is further interfaced with a space-qualified FPGA, which process the data stream to provide the 3D point clouds. Some of the main building blocks of the PIC Receiver are shown in Figure 2.

2.2 Optomechanical System

The optomechanical system in the SPACIAL LiDAR serves different functions:

- Beam conditioning of the illumination laser.
- Collection of the return light.
- Conditioning of the return beam for optimal coupling into the PIC Receiver.

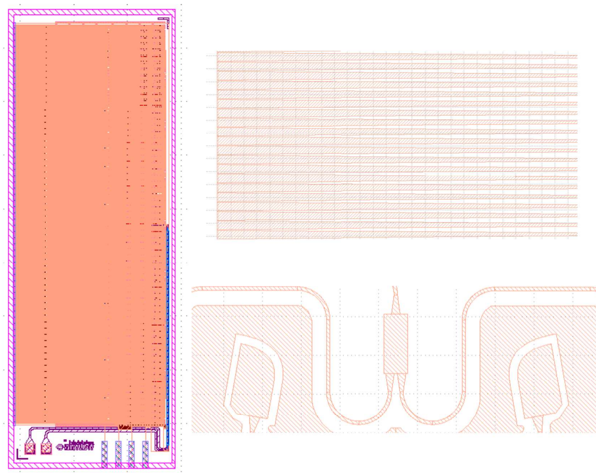

Figure 2. PIC Receiver building blocks: PIC form factor (left), waveguide tapers for the optical channels (top right), 1x2 splitters to distribute the local oscillator signal over the PIC (bottom right).

- Scanning of the illumination and line of sight of the PIC Receiver in the MSP.

A CAD model of the optomechanical system is reported in Figure 3. The optomechanical system has been designed following best-practice design methodology for optical system in space. The light coming from the fiber connected with the laser module passes first through an anamorphic negative lens ($Tx\,L_1$) which increases the divergence of the beam emitted by the fiber. With this lens the required angular coverage on the OSP (23 deg full angle) for the illumination beam can be achieved, and additionally it allows to reduce the total volume claim for the collimation on the MSP. Lens $Tx\,L_2$ in fact has the function to collimate the beam on the MSP to a beam diameter of about 60 mm and to correct eventual aberration introduced by $Tx\,L_1$. The transmitted beam is reflected by the beam scanner Mirror, where a rotation is introduced to fully scan the 23 deg field of view on the MSP. On the received path, the light is collected by $Rx\,M_1$ via a reflection to the beam scanner Mirror. With this construction, the rotating mechanism is actually on the common path of the transmitted and received beam, actually achieving coregistration on the MSP by design. $Rx\,M_1$ is a cylindrical parabolic mirror (parabolic profile on the MSP) with an effective MSP aperture of 60 mm. The choice of the aperture dimension matches the one of the illumination strip, which in turn it is determined by the requirement to have a collimated beam within the complete range of 1000 m. The reflection of the received beam on $Rx\,M_1$ implements a rotation of 90 deg, due to the off-axis design of $Rx\,M_1$, allowing to mount the PIC Receiver above the mirror, physically distancing possible thermal sources (electronics connected to the PIC Receiver) from $Rx\,M_1$.

The Beam Scanner subsystem is composed of a flat metal mirror actuated by a limited rotation Rotary Voice Coil. It is expected that potential noise sources stemming from the actuation of the voice coil are filtered by the inertia of rotating mass, and as such they do not constitute a problem in terms of pointing accuracy. The voice coil is connected to the rotating mirror by means of precision ball bearings. Based on TNO heritage in scanning mechanism for laser communication system in space,[3] this solution is considered the most reliable in terms of rotation accuracy. The latter is an important figure of merit for the system, since any spacial information about the relative position of an object in the scene on the MSP is extracted only from the information of the current position of the scanning system. To know this position accurately, and to enable a feedback control to reduce effect of vibration and drifts, magnetostrictive encoders are selected as candidate for mirror position sensors. This type of encoders are space qualified and experience with their use in space is already available.[3]

The housing and mechanical mounts of the optics are designed to be made in aluminium RSA-905. The same $Rx\,M_1$ is thought to be manufactured in RSA-905 with diamond turning for the reflecting parts. For the transmission optics, which is of refractive type, leaf spring flexures in the mounts are designed to allow for some elasticity to compensate the movement induced by thermal load on the system and by the difference in thermal expansion coefficients between glass and aluminium.

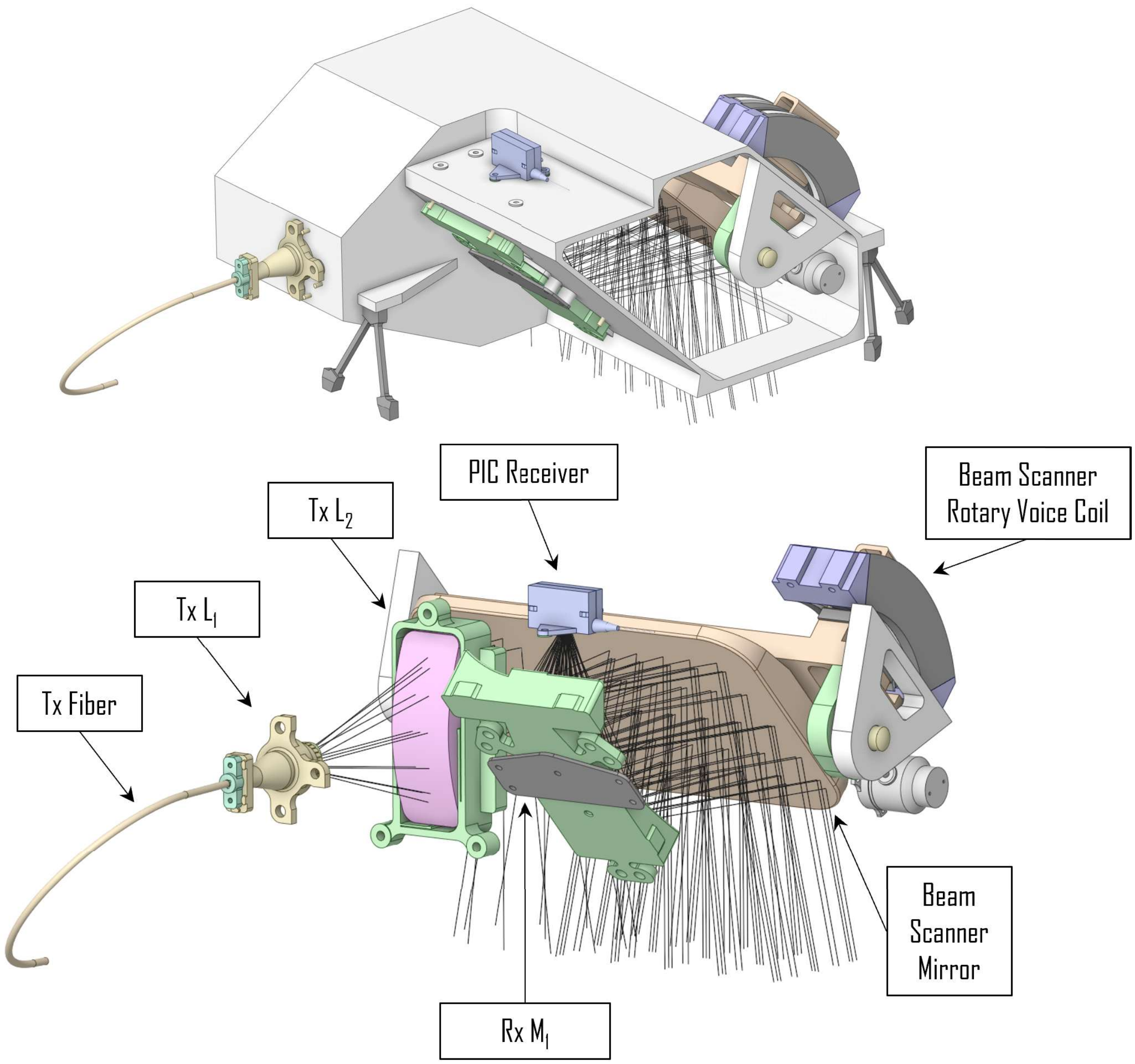

Figure 3. Optomechanical system of the SPACIAL LiDAR: 3D CAD view of the system within the housing provided with struts for mounting on a satellite platform (top); view of the optomechanical components within the housing, including the ray tracing of the optical paths (bottom).

3. CONCLUSION & OUTLOOK

This paper presents the design and the main specifications of the SPACIAL LiDAR, which is FMCW LiDAR for Lunar Landing. The system here presented is currently in a preliminary design phase, and the analyses conducted on the system, in terms of optomechanical tolerances and photon budget, show that the specifications of the system are feasible. As follow up of this activity, TNO and OMMATIDIA are currently performing breadboard testing which will allow to show the capabilities and the main functions of the system in a laboratory scale demonstrator.

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