A Multi-Functional Fiber Laser Lidar for Earth Science & Exploration

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Abstract:

A multi-pixel laser altimeter using pseudo-random-noise-modulated fiber lasers has been developed for Climate Change research and Exploration. The architecture supports a wide set of operational parameters (range resolution, range ambiguity interval, temporal update rate) without modifications to the hardware. These parameters can be changed dynamically, based on mission operational needs. The implementation is suitable for orbital and sub-orbital platforms and has reached TRL 6 having flown in a relevant environment over relevant terrain.

We will present the status of the instrument development efforts, the results from the on-going field campaign, and notional implementations for Earth Science Decadal Missions and Exploration.

Introduction:

The ability to quickly, easily and accurately measure glaciers, coastlines, forest canopies and other topographical features is the goal of many in the climate change and earth exploration communities. The Multi-Functional Fiber Laser Lidar (MFLL) system has been developed under a NASA IIP grant for doing exactly this job. The ITT design has followed three additional requirements: 1) cw laser operation, 2) an all-fiber optical chain and 3) no moving parts. While a radical departure from traditional pulse lidar systems, this approach provides advantages in reliability and technology readiness.

This paper discusses the MFLL instrument's system architecture, field and flight test results, geolocation technique, and technology infusion opportunities in multiple spaceflight missions.

System Architecture

The MFLL system is composed of 3 major parts: the Transmitter, Receiver, and Control and Data Handling subsystems shown in Figure 1.

Transmitter

The transmitter subsystem consists of the seed laser, amplifier, and pixel-painting optics. The seed laser is a Lumics 1064.178nm DBR whose 5mW output is directly modulated with a PN code. Previous generation systems included optical modulators which proved to be thermally temperamental. The seed is coupled to a 5W Ytterbium Fiber Amplifier whose output is chained to a custom Lightpath Technologies collimator with divergence of 2 mrad. This divergence provides a 1 meter ground sample spot at an altitude of 500m, a requirement set at inception of the program. The output then passes through a

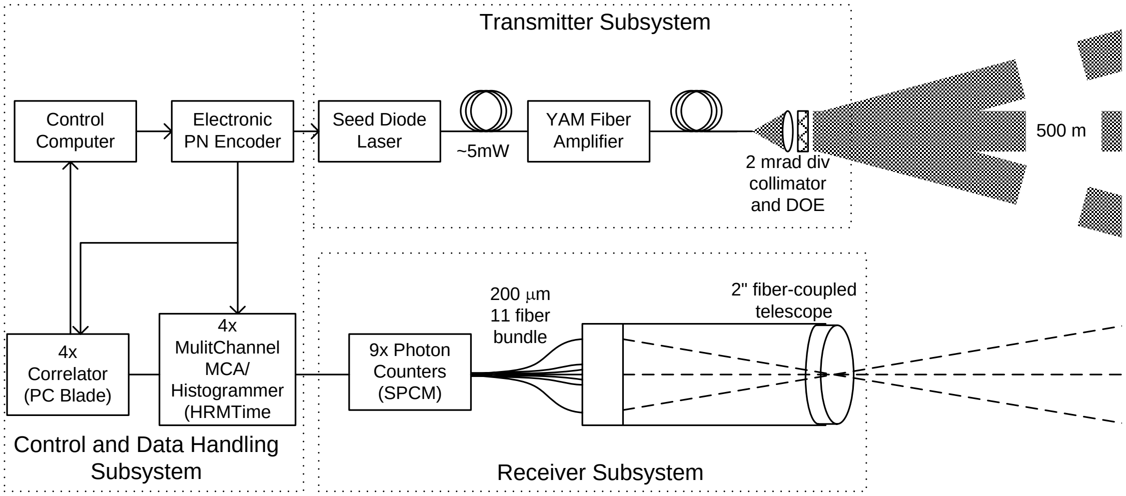

Figure 1: System Arcitecture

custom diffractive optical element used to split the beam into 11 output beams: four edge beams at ±2.75° horizontal and vertical, and five horizontal cross-track beams at multiples of ±0.2292° from nadir, shown in Figure 2.

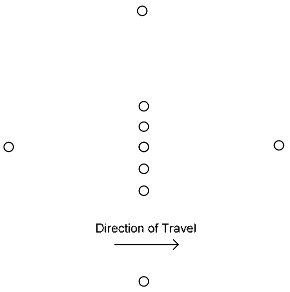

Figure 2: Laser Spot Pattern On Ground

Receiver

The receiver's optical chain consists of multiple spectral bandpass filters, a 2"diameter refracting 'telescope', a fiber array focal plane, and custom aft optics, terminating at a set of photon counting detectors. The spectral filters are placed at the entrance pupil of the telescope where reflected laser signal from 500m can be considered collimated. The stack of filters consisted of multiple 3nm wide CVI filters centered at 1064nm. The telescope is comprised of a single NIR doublet. As the object distance is only 500m, a true afocal design was not required and the performance of a simple doublet was determined to be more than adequate. The fiber array, placed at the focus of the doublet, was carefully designed to match the pattern of laser spots projected onto the ground. The doublet then couples the received laser signals into each corresponding fiber. At the output of each fiber is a set of matched asphere coupling optics and a Perkin Elmer SPCM detector. The output of the SPCM detectors are TTL signals which directly feed the SensL HRMTime modules discussed in the next section.

Data Handling

Our data collection computers simultaneously log the output of our Multi Channel Scalar-connected detectors and GPS/INS system, as well as provide real-time analysis and visualization. SENSL HRMTime multi channel scalars collect and bin the events produced by our detectors over many cycles of our PN code. The HRMTimes and NASA Ames' Applanix POSAV and Trimble DGPS systems all have simultaneous hardware-triggered outputs, which are recorded together in binary datafiles. For in-flight monitoring, we perform real-time correlation of our detected returns, retrieving calibrated range values and displaying them in LabView. Post processing and geolocation of our ranges is performed by another LabView codebase, operating on those raw datafiles.

<u>Field Trials</u>

Field trials have been conducted at the ITT Laser Test Range and from a Beech 90 Aircraft, courtesy of Dynamic Aviation.

Ground testing demonstrated our ability to a) align our transmitter and receiver, b) range at 250, 500, and 680 meters, c) demonstrate centimeter-stable instantaneous results and day to day repeatability.

Figure 3: Roofline Profile

The available static targets allowed us to calibrate out range biases across our pixels due to internal system delays.

Airborne testing confirmed the robustness of our instrument. MFLL was integrated into a Dynamic Aviation Beech 90 in Bridgewater, VA. NASA Ames Research Center provided GPS/INS support with Robert Billings on site (integrating their Applanix POSAV and Trimble DGPS systems), and an additional team for post processing. William Krabill of NASA Wallops, also provided his field-proven dual Ashtech Z-12 GPS system for further post-processing. While the final GPS/INS data are still post-processing, the instantaneous data provided a base-level check of our data. When overlaid with Google Earth imagery, buildings' rooflines are easily traced, visible in Figure 3.

Our skilled pilots [Steve and Jessi HELP WITH NAMES] flew meter-accurate ground tracks over Smith Mountain Lake, providing us with mountainous contours. Additional tracks over Wallops Island will allow for comparison with previously flown ranging instruments. As sand and ice present very similar spectral reflectivity, this allowed us to vette our system in a relevant environment for much colder missions.

Geolocation Technique

Geolocating LIDAR data infolves a geometric transform from the aircraft reference frame (defined by the Applanix IMU) to the ground reference frame (defined by the WGS84 datum). Novel to the ITT approach was the method for removing the pointing bias angles between the IMU and LIDAR optics.

Typically for imaging systems, resolvable surveyed points on the ground are used to determine the offset from the plane normal vector to the sensor normal vector. For a LIDAR like MFLL, these surveyed points would have to be three dimensional. MFLL utilized ranges measured by the outlying fore, aft, and cross-track pixels to calculate a linear angle of the earth under the plan in the pitch and roll directions, shown in Figure 4.

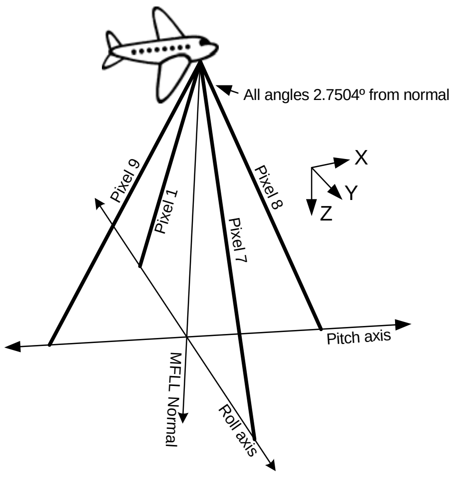

Figure 4: Geoloation Technique

By flying over water and averaging over several wave periods, the angle in roll and pitch components can be calculated. Two different missions involved flights over water. The first was an inland lake in western Virginia, and the second was the Atlantic Ocean and eastern Virginia. The Applanix pitch and roll data is compared to the pitch and roll data as calculated by the above method. The difference between the two is the bias angle, and can be removed through more typical geolocation transforms.

Technology Infusion Opportunities

Many opportunities for integrating MFLL technology and techniques lay ahead. MFLL's all-fiber, no-moving parts optical chain is very suitable for continuous operation aboard UAV platforms, such as Climatehawk. The scalability and reliability of CW fiber lasers lends MFLL system architecture to fill orbital ranging needs, like those presented by the ASCENDS mission. Similarly, bias-angle removal techniques can be employed to solve geolocation difficulties discovered by orbital platforms such as ICESAT. These same aspects suggest MFLL technology be used by ALHAT for ranging and surface-mapping lunar regolith.

Future investigations look to implement and document MFLL's usefulness in a wide variety of missions. While the present transmitter is presently implemented using a fiber amplifier at 1μm, it can be just as easily implemented at optimal wavelengths for vegetation, ice sheet topography, bathymetry, aerosols, clouds, lunar and planetary surfaces. Robust fiberoptic transmitters are available today at wavelengths ranging from 1um to just over 2µm, and development of new capabilities continues at a rapid pace. Shorter wavelengths are reached by modulating an existing laser diodes or by using second harmonic generation techniques. Longer wavelengths can be reached using Interband-Cascade and Quantum-Cascade laser diodes. The receiver design also lends itself to be upgraded. The fiber puck focal plan can be interfaced to a growing variety of detectors, or even replaced with a large-pixel focal plane array.

Conclusion

The MFLL instrument has demonstrated multi-pixel ranging and mapping capability from an airborne platform. While final measurements are still being compiled, static measurements demonstrate ranging error on the order of centimeters. Novel pixel arrangements have helped maximize geolocation accuracy. MFLL's robust hardware lends it to unmanned and space missions, and its adaptable architecture suggests many applications worth investigating.

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