SCANNING, PHOTON-COUNTING LIDARS FOR LARGE-SCALE, HIGH RESOLUTION, TOPOGRAPHIC MAPPING FROM HIGH ALTITUDES

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ABSTRACT

Photon-counting 3D imaging lidars are the most efficient, requiring only a single detected photon to record a range measurement. The first successful photon-counting airborne laser altimeter was demonstrated under NASA's Instrument Incubator Program (IIP)[1]. Although the tiny microchip laser transmitter emitted only 2 µJ in a few kHz train of 600 psec pulses, the "micro-altimeter" successfully recorded single photon ground returns in daylight from altitudes as high as 6.7 km on its first engineering flight on the morning of 4 January 2001 at roughly 10:30 am. The RMS range scatter off flat surfaces and rooflines was typically about 5cm. The instrument also demonstrated an ability to record tree canopy heights relative to the underlying terrain and, due to its operating wavelength of 532 nm, to perform shallow water bathymetry at depths up to 3 m. The lidar was later equipped with a conical scanner to generate rudimentary 3D images.

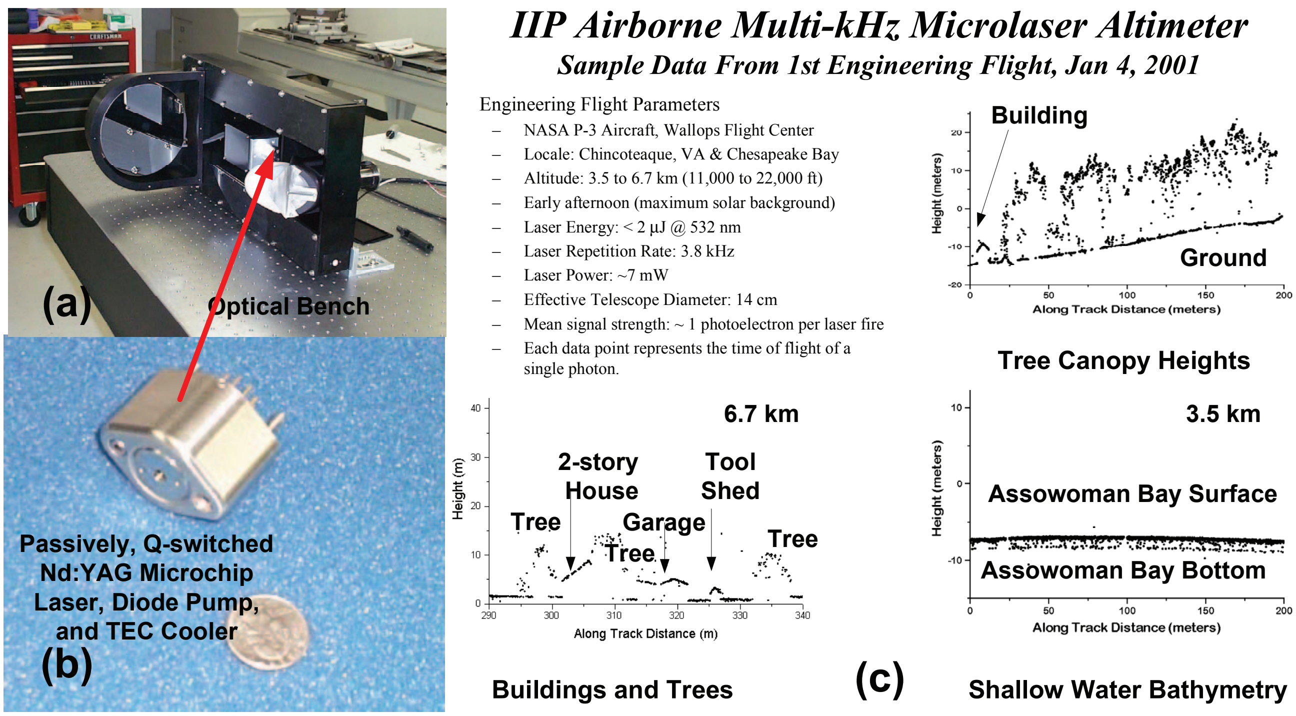

Figure 1: (a) 1st Generation Photon-Counting NASA Microaltimeter Optical Bench; (b) Microchip Laser Transmitter and Pump; (c) Sample 2D-profiling data from first engineering flight taken between 10 and 11 am at altitudes between 3.5 and 6.7 km.

Sigma Space Corporation subsequently developed a 2nd generation, high spatial resolution lidar for use in small aircraft or mini-UAV's. From altitudes of 1 km, the lidar generates contiguous 3D topographic maps with 15 cm horizontal and few cm vertical (range) resolution [2]. A frequency-doubled Nd:YAG microchip laser produces a 22 kHz train of 6 µJ, sub-nanosecond pulses at 532 nm. A Diffractive Optical Element (DOE) breaks the beam into a 10x10 array of beamlets, each consisting of a 22 kHz train of 50 nJ pulses, which corresponds to roughly 1 mW of laser power per channel. The individual beamlets are then imaged by the 7.5 cm aperture receive telescope directly onto individual pixels of a focal plane array detector. Each pixel is then input to one channel of a 100 channel timer for a 2.2 Megapixel/sec 3D imaging rate. The unique multiple stop capability of the detector and range receiver permits daylight operation with large range gates and enhances penetration of ground fog, dust, water columns(for underwater 3D imaging), and tree canopies (for forest management and biomass estimation). The dual wedge optical scanner characteristics are tailored to provide contiguous coverage of a ground scene in a single overflight. Recent flight tests have produced outstanding 3D images as in Figure 2.

Because of their high efficiency, photon-counting systems can be more easily scaled to high altitude aircraft or spacecraft than conventional multi-photon lidars [3]. In fact, the technology exists today to support wide swath , contiguous, meter resolution mapping from aircraft altitudes 12 km and higher in support of national mapping or surveying campaigns. For example, swath widths on the order of 10 km can be mapped with horizontal resolutions of 2 to 3 m. Assuming a nominal aircraft velocity of 800 km/sec, this corresponds to an areal mapping rate of 8000 km^2/hr. Trading swath width for higher resolution is also possible.

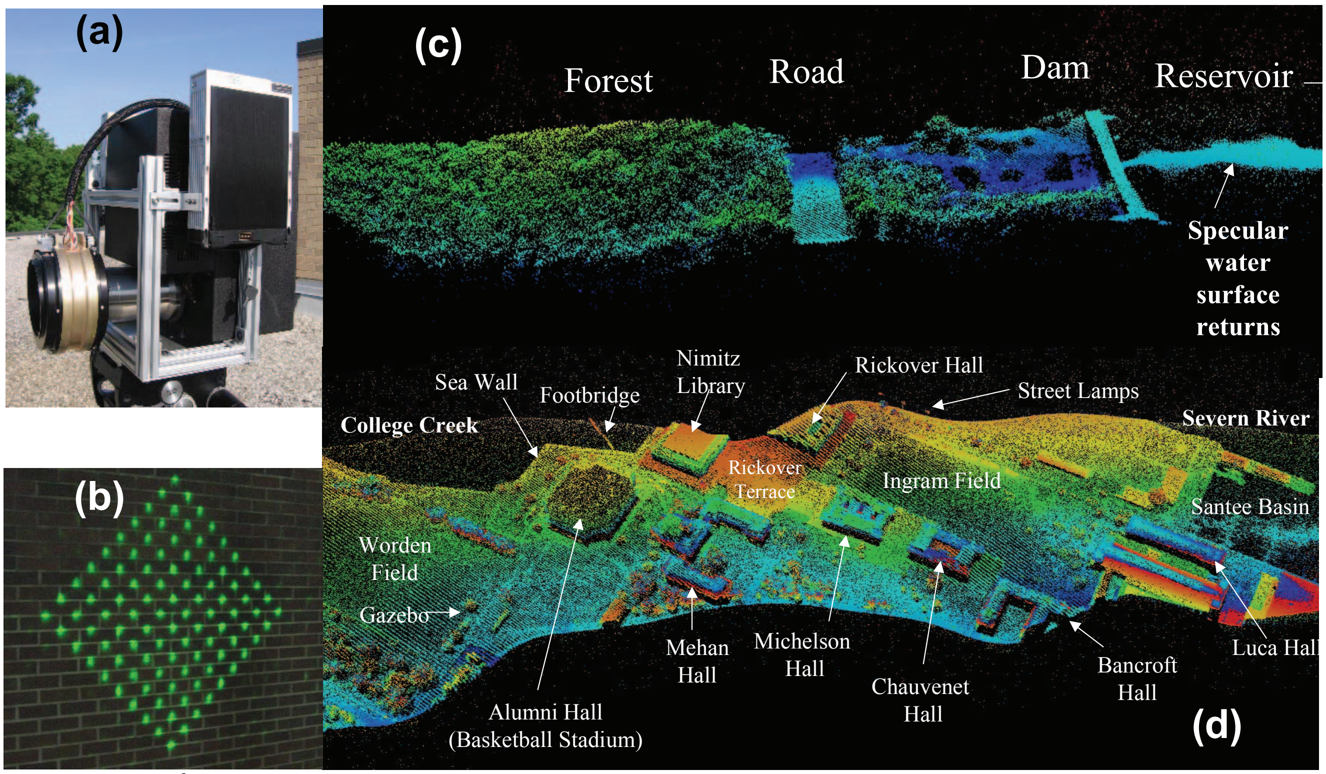

Figure 2: (a) 2nd Generation 3D Imaging Lidar; (b) 10x10 beamlet pattern generated by DOE; and daytime 3D lidar images of (c) Triadelphia dam and reservoir in Howard County, MD and (d) US Naval Academy campus in Annapolis, MD.

A feasibility study, recently conducted by Sigma for NASA's Jupiter Icy Moons Orbiter (JIMO) mission, indicated that an upgraded version of the 2nd generation lidar, could globally and contiguously map all three of Jupiter's primary moons – Ganymede, Callisto, and Europa – in a matter of months with a Power-Aperture product of only TBD $W\text{-}m^{2}$. This analysis assumed a nominal 100 km orbit about the various moons with few meter horizontal resolution and sub-decimeter vertical (range) resolution., Sigma is presently developing and lifetesting technologies for a 16-beam photon-counting Cross Track Channel (CTC) Lidar designed to piggyback with the primary lidar on NASA's ICESat-II, operating from an Earth orbital altitude of 600 km.

REFERENCES

[1] J. Degnan, J. McGarry, T. Zagwodzki, P. Dabney, J. Geiger, R. Chabot, C. Steggerda, J. Marzouk, and A. Chu,"Design and performance of an airborne multikilohertz, photon-counting microlaser altimeter", Int. Archives of Photogrammetry and Remote Sensing, Vol. XXXIV-3/W4, pp. 9-16, Annapolis, MD, 22-14 Oct. 2001.

[2] J. Degnan, R. Machan, E. Leventhal, G. Jodor and C. Field, "Inflight Performance of a Second Generation, Photon-Counting 3D Imaging Lidar", SPIE Defense and Security 2008, Orlando, FL, March 17-20, 2008.

[3] J. J. Degnan, "Photon-Counting Multikilohertz Microlaser Altimeters for Airborne and Spaceborne Topographic Measurements", Journal of Geodynamics (Special Issue on Laser Altimetry), pp.503-549, November, 2002.