FUSION: A FULLY ULTRAPORTABLE SYSTEM FOR IMAGING OBJECTS IN NATURE

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1. INTRODUCTION

To improve satellite-derived estimates of terrestrial plant production and exchange of CO_2, water, and energy with the atmosphere, scientists need to consider ecosystem composition, structure, function, and health. This can be accomplished through the fusion of Light Detection And Ranging (LiDAR) data, which can provide 3D information about the vertical and horizontal distribution of vegetation [1,2,3,4,6,7,9]; and hyperspectral remote sensing, which can inform us about variations in biophysical variables (e.g., photosynthetic pigments) and responses to environmental stressors (e.g., heat, moisture loss) [3,5,8,10]. Satellite observations from upcoming Decadal Survey missions [11] will provide NASA with the unique opportunity to fuse LiDAR data from ICESat-II, DESDynI, and LIST with hyperspectral and thermal imagery from HyspIRI and GEO-CAPE. This synergy will augment and enhance the individual science objectives of decadal survey missions, and will allow scientists the opportunity to develop 3D models of plant canopies that better describe global cycling of carbon, water and energy. Multiple NASA's Earth Science Focus Areas are served by this science, including carbon cycle and ecosystems; water and energy cycle; and climate variability and change (i.e., ecosystem responses and feedbacks to climate change).

One of the major obstacles to the development of data fusion algorithms is the availability of accurately co-registered data of similar grain size [1]. This is often the case when instruments are flown on different platforms and at different times during a field campaign. We believe that "instrument fusion" is a prerequisite to "data fusion", and we have developed a system the integrates a full-waveform LiDAR, narrow band hyperspectral imager, and broad band thermal imager in a single, compact and portable instrument package that could be readily deployed on a number of observation platforms. FUSION will provide accurate co aligned datasets that are needed for: (i) calibration and validation of satellite-derived land products; (ii) development of data fusion algorithms; and (iii) combine observations from multiple sensors to characterize ecosystem composition, structure, function, and health.

2. SYSTEM COMPONENTS

2.1 Visible to Near Infrared (VNIR) Imaging Spectrometer

The hyperspectral imaging component of FUSION is comprised of the Hyperspec™ VNIR Concentric Imaging Spectrometer (Headwall Photonics, Fitchburg, MA) and the ruggedized RA1000m/D digital fine gain imaging camera (Adimec, Stoneham, MA). The Hyperspec spectrometer enables high spectral and spatial resolution imaging through high efficiency f/2.0 telecentric optics and a high efficiency aberration-corrected convex holographic diffraction grating, providing an optical dispersion of 100 nm per mm over a 7.4 mm spatial by 6.0 mm spectral focal plane. The concentric spectrograph, based on the Offner design, enables imaging from 400-1000 nm over the full extent of an 18 mm tall user interchangeable entrance slit. The standard slit width used in this work was 12.5 microns wide, yielding a 1.29 nm spectral resolution. Hyperspec imaging spectrometer

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accepts a C-mount objective lens that is field interchangeable, providing the ability to vary the FOV and IFOV. Camera features include: a digital fine gain for adjustable camera sensitivity over a 60 dB dynamic range, electronic shuttering, low smear characteristics, and offers ruggedized military specifications for severe operating environments. Image acquisition, motion control, and hyperspectral data cube generation are accomplished through the customized Hyperspec™ acquisition software with LabVIEW executable graphic user interface.

2.2 Light Detection and Ranging (LiDAR)

In 2010 the LiDAR components of FUSION will be upgraded from the Riegl LD90 single point laser range finder [9] with the LD321-A40 single point waveform laser range finder operating at 2500 Hz. This portion of the system will accurately measure the distance between the canopy top (minimum distance function) and ground elevation (maximum distance function) along with the vertical distribution of intercepted surfaces within a range of 470 m with an accuracy of ± 20 mm. The IEC and ANSI Class 1 Eye safe infrared beam emits at 930 nm with a beam divergence of 1.8 mrad after collimating optics to yield a 0.18 cm beam diameter per meter of distance. TCP/IP and RS232/RS422 ports allow for fast and versatile data output configurations for constructing a fully integrated system composed of multiple sensors and large data volumes. Instead of 3D point clouds, more detailed and additional information are provided about the structure of the illuminated surfaces through the backscattered waveform analysis. In vegetated areas, more 3D points may be extracted, low vegetation can be separated from ground and both canopy and ground heights can be measured with higher accuracy.

2.3 Thermal Imaging

The thermal imaging component of FUSION will be added in 2010 with initial results exhibited in the IGARSS proceedings manuscript. Xenics Gobi thermal imager is a compact light weight broad band (8 to 14 μm) ruggedized thermal imager with a 384 by 288 pixel uncooled microbolometer array. The system offers a 16 bit resolution at 25 Hz and can operate under extreme conditions from -40°C to +50°C and withstand a 2 G vibration and 70 G shock. The camera has sufficient resolution and accuracy to measure target thermal properties with a ≥ 50 mK sensitivity. Image data can be transferred to the acquisition computer through CameraLink or Ethernet digital interfaces.

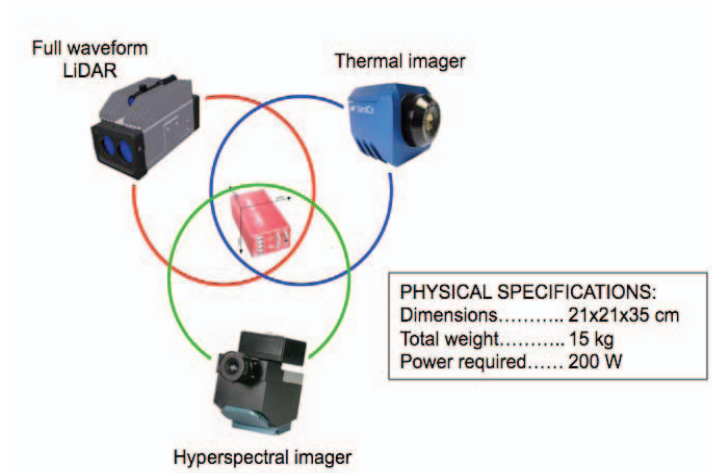

Figure 1. *FUSION* integrates off-the-shelf instruments (TRL ≥8) and a single solution GPS/IMU in a compact and lightweight package.

3. TOWER OPERATION

The system was operated June – July, 2009 on a forest tower located at the Smithsonian Environmental Research Center (SERC) in Edgewater, MD which contains an extensive hardwood forest tract of 2 km continuous mature poplar dominated mixed forest with a maximum height of about 40 meters (Fig. 2, left). The leaf-area density distribution has understory and overstory peaks, which makes this site an excellent case study. FUSION was mounted in a co aligned optical configuration measuring 21x21x35 cm and attached to a heavy duty programmable pan-tilt unit (DP300, Directed Perception, Burlingame, CA). The DP300 pan tilt unit enabled push broom hyperspectral data collection with a user selected pan increment up to 360° continuous and tilt view zenith from 0° to 120°. Both pan and tilt axis have an adjustable speed up to 22° per second with 0.00625° position accuracy. A co-regisetered segment of the FUSION acquisition is shown as a true color image with three regions of interest (Fig. 2, top center). Region (A) is a far field oak dominated sunlit crown with a mean range of 28 m from the instrument. The second region (B)

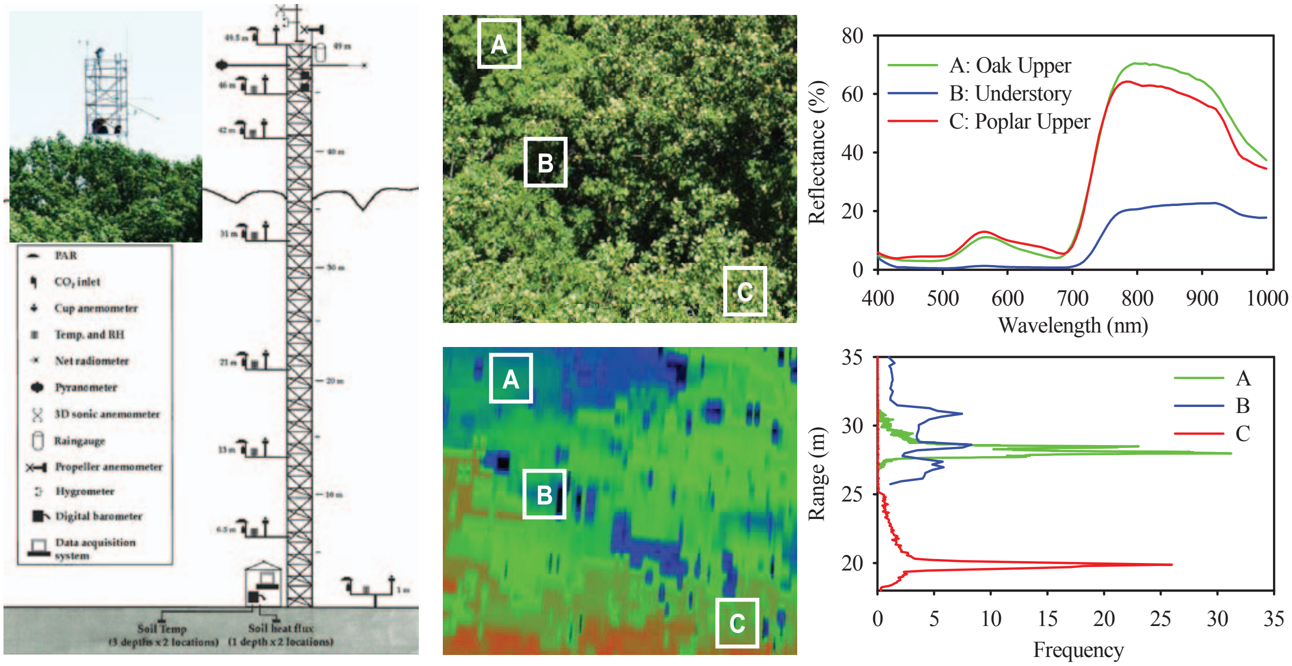

Figure 2. FUSION data acquisition from SERC tower (left). True color image (top middle) and LIDAR false color composite (bottom middle) with three varying canopy regions of interest labeled A through C. Reflectance spectra averaged from each region of interest (10K pixels) are shown in upper right along with frequency distributions for LIDAR average returns (bottom right).

is dominated by shaded understory with a wide range of LiDAR returns from 26 to 35 m. The third region (C) is a near field poplar dominated sunlit upper crown with a mean range of 20 m. The square defining each region is 100 X 100 pixels yielding 10,000 pairs of spectra and LIDAR data points. Mean spectra for each region are plotted in Figure 2 (top right). The sunlit upper oak and poplar upper tree crown has similar spectral features with the oak having a higher NIR reflectance than poplar. The converse is observed in the green and yellow region from 500 to 675 nm which is most likely attributed to the poplar blossoms. The shaded understory region (C) has a dramatically reduced signal with the NIR region yielding only 20% reflectance.

4. FUTURE DIRECTIONS

FUSION once fully developed will integrate full-waveform LiDAR, narrow band hyperspectral imagery, and broad band thermal imagery in a single, compact and portable instrument package that could be readily deployed on NASA suborbital aircraft (Fig. 3). The fully integrated airborne system will utilize a single solution GPS/IMU subsystem to provide accurate georeferenced datasets. The Twin Otter aircraft supported by the NASA Airborne Science Program operating out of GSFC-WFF provides a suitable platform for initial flight tests of FUSION. The high wing twin engine aircraft is capable of low altitude and relatively slow airspeeds. In addition, the Viking 400 UAV operated by BAI Aerosystems, Easton MD has been identified as a suitable unmanned flight platform using; GPS waypoint navigation, a 60 lb payload capacity with 7,000 cubic inches of payload volume.

NASA decadal survey missions using LiDAR (DESDynI, ICESat-II, LIST) and hyperspectral imaging (HyspIRI, GEO-CAPE) provide complementary data for achieving NASA's Earth Science objectives, including those related to terrestrial ecosystem processes and the global carbon cycle. These include remote sensing of land cover/use, quantification of plant biomass, and assessment of vegetation health for predicting plant productivity. A large number of data fusion studies have been conducted with data from independent airborne sensors, but co-registration errors and temporal uncertainties can be problematic when these instruments are flown on different platforms or acquired on different dates/times. A fully integrated multi-sensor system would help reduce these errors and uncertainties, and would increase productivity and reduce data acquisition costs by lowering the number of flight hours, eliminating the need for redundant GPS/IMU subsystems, and streamlining the data acquisition and data processing workflow.

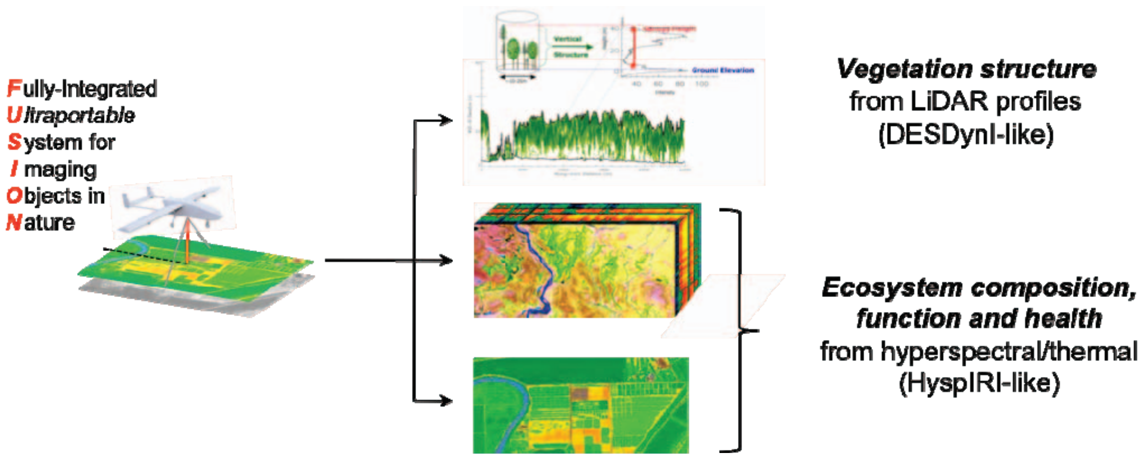

Figure 3. Fusion of 3D LiDAR data and 2D hyperspectral/thermal imagery will provide synergistic data for studying ecosystem structure and function along with satellite calibration/validation activities.

5. REFERENCES

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