Applying Model Predictive Control Architecture for Efficient Autonomous Data Collection and Operations on Planetary Missions. M. D. Lieber[1], E. Schindhelm[1], S. E. Roark[1], R. Rohrschneider[1], J. D. Weinberg[1], and C. Weimer[1], [1]Ball Aerospace, 1600 Commerce St., Boulder, CO 80301 (mlieber@ball.com).

Introduction: Planetary Science missions stand to benefit from recent developments in miniaturization of satellite technology (e.g. CubeSats) and increased on-board automation [1]. Whether utilizing onboard processes to automate instrument and spacecraft operations or to controlling a network of Smallsats, balloons, or rovers, automation can optimize both power utilization and the science data collection process. Through NASA-ESTO funding, we have developed algorithms that support optimized data collection from space using an architecture based upon Model Predictive Control (MPC). MPC is an ideal framework for autonomous, real-time control of complex systems because it re-optimizes with respect to multiple goals and constraints at every time step. Because of this proven capability, it is often the starting point for software control architecture design of many terrestrial applications including autonomous cars, robotic vision systems and it has been proposed for control of distributed spacecraft.

Without increased on-board autonomy, communication time-delays provide a natural limit on the efficiency and quality of science data collection. In this presentation, we expound upon both the fundamentals of the MPC-based approach with its ability to incorporate hierarchical and distributed elements and also the computational challenges. Applications include autonomous control of formations of Cubesats, interrogation of underground structures or caves and adaptive instruments for information collection.

Background: On-board systems for real-time control of instruments have been limited in general to a few traditional architectures. This is due to several factors: an understandable conservatism in approach, a history of constraints on computational resources, a perceived lack of need for greater sophistication or autonomy, and hardware capable of leveraging additional actuation degrees-of-freedom. However, technological advancements over the past decade have increased the availability of ever more powerful and inexpensive computational hardware to enable adaptive instrument operation while miniaturization has made feasible a new class of space missions built around SmallSat and CubeSat platforms. For complex systems in general, these developments have driven a shift in focus from classical control theory to advanced, optimization-based control methods. An example of this architecture is shown in Figure 1 including a real-time scene classifier.

Lab demonstration: As an example of this technology, under NASA funding, we have developed and laboratory tested a real-time adaptive instrument - a multi-beam flash lidar with 2D, individually steerable beamlets (power level and direction vector). This implementation was meant to be on an orbiting platform as shown schematically in Figure 2. More details can be found in reference [2]. The laboratory implementation with scene projection, shown in Figure 3, utilizes a spatial light modulator for real-time multi-beam targeting. The A key component is a real-time scene classifier which uses multiple spectral bands to make decisions as to lidar beam targeting. Included is a graphical user interface to vary the projected scenes (in this case, multi-color Earth scenes).

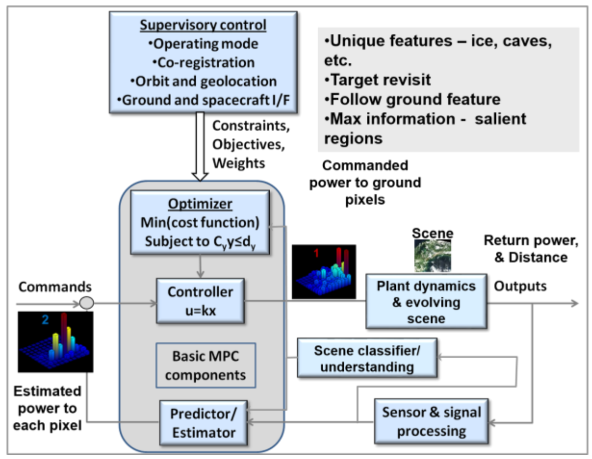

Figure 1 – MPC architecture with targeted multi-beam lidar application.

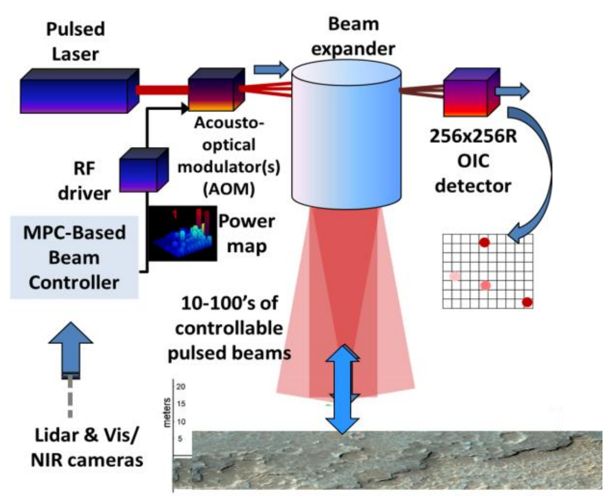

Figure 2 – Multi-beam, adaptive lidar beam using MPC-based controller for optimal digital terrain mapping.

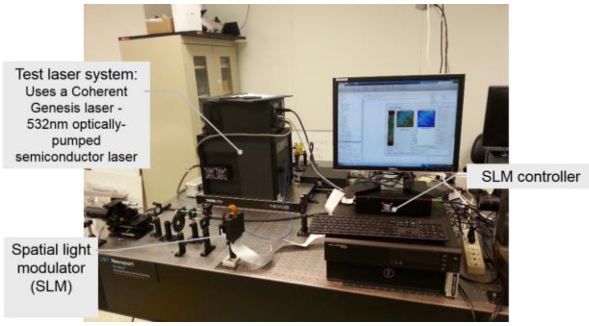

Figure 3 – Laboratory testing of MPC-based control of a multi-beam adaptive lidar with scene projection and multi-spectral scene classification.

The software has been demonstrated to a Technology Readiness Level (TRL) 4 for the adaptive lidar, but because of the top-down approach, can be readily re-purposed to adaptive real-time control for multiple instruments and spacecraft around planetary bodies. Beyond the targeted application, MPC provides an architecture for controlling formation flying CubeSat swarms performing unique surface or atmospheric measurements, or tiered systems of platforms for remote exploration. Onboard science operations can be automated to direct collection, prioritization, compression, and downlink of data.

Future development: The MPC architecture is known to require extensive computations to enable re-optimization of the objective goal at each time step. Newly developed heterogeneous computing platforms and fast algorithms have enabled the growth of this technology into many new areas. Simulataneously, new developments in intelligent processing, such as deep learning, which is a complementary technology, have made real-time scene understanding and classification more realizable and will be explored in future work. Another feature that was developed was the capability to operate in a data driven mode rather than rely upon previous models and will also be addressed in a future paper.

References: [1] J. D. Weinberg, S. Petroy, S. E. Roark, E. Schindhelm, 2018, 49th LPSC, [2] M. Lieber, C. Weimer, R. Rohrschneider, L. Ruppert., 2017, AAS GNC, AAS 17-123.