Reactive Sequencing for Autonomous Navigation Evolving from Phoenix Entry, Descent, and Landing

Dr. Christopher A. Grasso*
Jet Propulsion Laboratory / California Institute of Technology / Blue Sun Enterprises, Boulder, Colorado, 80302

and

Joseph E. Riedel†
Andrew T. Vaughan‡
Jet Propulsion Laboratory / California Institute of Technology, Pasadena, California, 91109

I. Introduction

Virtual Machine Language (VML) is an award-winning advanced procedural sequencing language in use on NASA deep-space missions since 1997, and was used for the successful entry, descent, and landing (EDL) of the Phoenix spacecraft onto the surface of Mars. Phoenix EDL utilized a state-oriented operations architecture which executed within the constraints of the existing VML 2.0 flight capability, compatible with the linear "land or die" nature of the mission. The intricacies of Phoenix EDL included the planned discarding of portions of the vehicle, the complex communications management for relay through on-orbit assets, the presence of temporally indeterminate physical events, and the need to rapidly catch up four days of sequencing should a reboot of the spacecraft flight computer occur shortly before atmospheric entry. These formidable operational challenges led to new techniques for packaging and coordinating reusable sequences called blocks using one-way synchronization via VML sequencing global variable events. The coordinated blocks acted as an ensemble to land the spacecraft, while individually managing various elements in as simple a fashion as possible.

This paper outlines prototype VML 2.1 flight capabilities that have evolved from the one-way synchronization techniques in order to implement even more ambitious autonomous mission capabilities. Target missions for these new capabilities include autonomous touch-and-go sampling of cometary and asteroidal bodies, lunar landing of robotic missions, and ultimately landing of crewed lunar vehicles. Close proximity guidance, navigation, and control operations, on-orbit rendezvous, and descent and landing events featured in these missions require elaborate abort capability, manifesting highly non-linear scenarios that are so complex as to overtax traditional sequencing, or even the sort of one-way coordinated sequencing used during EDL. Foreseeing advanced command and control needs for small body and lunar landing guidance, navigation and control scenarios, work began three years ago on substantial upgrades to VML that are now being exercised in scenarios for lunar landing and comet/asteroid rendezvous. The advanced state-based approach includes coordinated state transition machines with distributed decision-making logic. These state machines are not merely sequences - they are reactive logic constructs capable of autonomous decision making within a well-defined domain. Combined with the JPL's AutoNav software used on Deep Space 1 and Deep Impact, the system allows spacecraft to autonomously navigate to an unmapped surface, soft-contact, and either land or ascend. The state machine architecture enabled by VML 2.1 has successfully performed sampling missions and lunar descent missions in a simulated environment, and is progressing toward flight capability.

The authors are also investigating using the VML 2.1 flight director architecture to perform autonomous activities like rendezvous with a passive hypothetical Mars sample return capsule. The approach being pursued is similar to the touch-and-go sampling state machines, with the added complications associated with the search for, physical capture of, and securing of a separate spacecraft. Complications include optically finding and tracking the Orbiting Sample Capsule (OSC), keeping the OSC illuminated, making orbital adjustments, and physically capturing the OSC. Other applications could include autonomous science collection and fault compensation.

* Principal VML Engineer, Blue Sun Enterprises, 1942 Broadway Suite 314, Boulder, CO, 80302, Prof. Member.
† Principal Engineer, Optical Navigation, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA, 91109.
‡ Senior Engineer, Optical Navigation, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA, 91109.