Lunar Reconnaissance Orbiter (LRO) Thruster Control Mode Design and Flight Experience

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National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center (GSFC) in Greenbelt, MD, designed, built, tested, and launched the Lunar Reconnaissance Orbiter (LRO) from Cape Canaveral Air Force Station on June 18, 2009. The LRO spacecraft is the first operational spacecraft designed to support NASA's return to the Moon, as part of the Vision for Space Exploration. LRO was launched aboard an Atlas V 401 launch vehicle into a direct insertion trajectory to the Moon. Twenty-four hours after separation the propulsion system was used to perform a mid-course correction maneuver. Four days after the mid-course correction a series of propulsion maneuvers were executed to insert LRO into its commissioning orbit. The commission period lasted eighty days and this followed by a second set of thruster maneuvers that inserted LRO into its mission orbit. To date, the spacecraft has been gathering invaluable data in support of human's future return to the moon.

The LRO Attitude Control Systems (ACS) contains two thruster based control modes: Delta-H and Delta-V. The design of the two controllers are similar in that they are both used for 3-axis control of the spacecraft with the Delta-H controller used for momentum management and the Delta-V controller used for orbit adjust and maintenance maneuvers. In addition to the nominal purpose of the thruster modes, the Delta-H controller also has the added capability of performing a large angle slew maneuver.

A suite of ACS components are used by the thruster based control modes, for both initialization and control. For initialization purposes, a star tracker or the Kalman Filter solution is used for providing attitude knowledge and upon entrance into the thruster based control modes attitude knowledge is provided via rate propagation using a inertial reference unit (IRU). Rate information for the controller is also supplied by the IRU. Three-axis control of the spacecraft in the thruster modes is provided by eight 5-lbf class attitude control thrusters configured in two sets of four thrusters for redundancy purposes. Four additional 20-lbf class thrusters configured in two sets of two thrusters are used for Lunar Orbit Insertion maneuvers. The propulsion system is one the few systems on-board the LRO spacecraft that has built in redundancy.

The Delta-H controller consists of a Proportional-Derivative (PD) controller with a structural filter on the thrusters and a Proportional controller on the reaction wheels. The PD control that employs the thrusters is used for attitude and rate control. The Proportional controller on the reaction wheels is used for commanding the wheels to a new momentum state. The ground commands used for the Delta-H controller are the system momentum vector, reaction wheel momentum, maximum expected command time, and which set of attitude control thrusters to use.

The ability to command both the system momentum vector and reaction wheel momentum in the Delta-H controller provides both a capability and an additional source of operator error. Large angle slews via the Delta-H controller is achievable via this commands because these commands are used for the exit mode criteria. Setting these commands to non-consistent values prevents the mode from exiting nominally.

The Delta-V controller consists of a Proportional-Integral-Derivative (PID) controller with a structural filter on the thrusters and a Proportional controller on the reaction wheels. The PID controller is used for maintaining attitude and rate performance during the maneuver. The Proportional controller on the reaction wheels is used for maintaining wheel speed during the maneuver. The ground commands used for the Delta-V controller are

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mode time, Delta-V amount, which set of attitude control thrusters to use, which set of insertion thrusters to use, and the operational mode of the attitude control thrusters.

One additional feature of the Delta-V controller is the inclusion of a feed-forward torque command. The feed-forward torque command is used to reduce the initial transients due to the motion of the center of mass between thruster maneuvers. The benefits of the feed-forward torque command is discussed in more detail in the paper.

This paper discusses the design of the Delta-H and Delta-V controllers, as well as the constraints and performance requirements placed on the two controllers. Items of the mode design that are discussed include the thruster distribution logic, feed-forward torque in the Delta-V controller, reaction wheel control philosophy, and the use of an integrator in the Delta-V control loop. This is followed by a more detailed discussion of the on-orbit performance of the thruster modes and the effectiveness of the design choices from launch through the first few station-keeping maneuvers.