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A NONLINEAR ADAPTIVE ATTITUDE OBSERVER FOR SPACECRAFT WITH GYROS SUBJECT TO THERMALLY-VARYING BIASES

Abstract

Attitude and angular rate measurements are critical for spacecraft Guidance, Navigation, and Control (GNC) systems. As pointing control requirements for missions become ever more stringent, attitude noise estimation and cancellation algorithms that can improve attitude estimates with the same sensors become more desirable. Noise cancellation techniques are also attractive for nanosats which typically use noisy MEMS IMUs to meet cost, power, and size constraints. Popular algorithms to estimate spacecraft attitude, such as Multiplicative Extended Kalman Filters (MEKFs), can be augmented to attempt to learn and cancel sensor bias, but MEKFs can not be proven to converge to true bias. Experience shows that their performance at bias cancellation is weak, especially when the bias is correlated to an unaccounted for state such as temperature. This may have been the case in the GNC system of the Solar Dynamics Observatory which had gyro bias oscillations when it's gyro heaters were disabled.

A new algorithm based on an existing approach is proposed to estimate thermally-varying gyro biases for rigid body vehicles. Gyro temperature biases are approximated with a finite number of basis functions over a pre-set temperature range. The approximations are shown, via a Lyapunov analysis, to converge exponentially fast to a large class of thermally dependent gyro biases if a persistency of excitation condition is met. Even if the persistency of excitation condition is not met, the temperature bias is shown to converge exponentially fast to the true value for the temperatures encountered. The existing approach's capability to handle gyro scale factor error and misalignment error are preserved under this new and original algorithm.

Simulation results of a spacecraft with an angular rate gyro and a star tracker is given. The simulation illustrates the theoretical claims of the nonlinear observer under the various conditions detailed above. Each simulation also provides a direct comparison with two MEKFs, one augmented to try to estimate constant gyro biases and one augmented to try to estimate temperature varying gyro biases.

This work provides several interesting areas for discussion, such as: What other types of noise in IMUs are limiting performance that might be addressed through this new type of filtering methodology? What type of demonstrations might be useful in spurring innovation in attitude estimation in a field that is dominated by the Kalman filter framework? What is needed to make nonlinear algorithms more accessible in mainstream GNC algorithm design?