KSC NIFS Intern Abstract: Simulation and Implementation of Advanced Space Vehicle Control Algorithms

Ryan Wallace

William E. Boeing Department of Aeronautics and Astronautics

University of Washington, Seattle

Under Mentorship of: Michael DuPuis

July 2, 2018

The works produced in this summer internship involved the development, simulation and analysis of guidance, navigation and control (GNC) systems constructed in the mathematical framework of dual quaternions for the purpose of quantifying their advantage compared to traditional GNC systems. The work did not build on any projects previously underway. This meant a mathematical foundation was needed to understand the properties of the dual quaternion and a literature review had to be conducted. For this reason, a large reference document was assembled to collect the mathematical properties and their proofs that were found in the literature. The dual quaternion equations of motion for ridged bodies were derived and a ridged body simulation was built in Simulink and Matlab along with an animation written in Matlab for visual aid. This simulation was tested, documented, and compared to a similar simulation produced by Dr. Sergey Drakunov.

To achieve the goal of the project, a useful set of comparison metrics were determined by researching the common methods of comparing algorithm performance such as time complexity, space complexity, accuracy, and others. As an exercise, the time complexity of three attitude representations, i.e. Euler angles, direction cosine matrices, and quaternions were computed and compared to gain familiarity with the technique. This exercise served as practice for the future when the same procedure has to be done for the dual quaternion architecture.

Then began the development of dual quaternion GNC (DQGNC) systems. The creation of a dual quaternion controller was attempted using linearization techniques but proved difficult due to the high nonlinearity of the dynamics and kinematics equations. Hence, nonlinear Lyapunov techniques were used to understand the dual quaternion controllers found in literature. These controllers were implemented in simulation with the ridged body simulation created previously, tested, analyzed and modified using the developed understanding of dual quaternion mathematics. Puzzling motion was created by one of the controllers and after further analysis, discussion with the project mentor and consultation with Dr. Drakunov, the motion was determined to be from the screw motion that minimizes the dual quaternion error norm. It was also proposed that proper guidance systems could be created to force desired motion in Euclidean space. Such a path planning system was then developed to force straight line translation by using an efficient real quaternion interpolation scheme (Quaternion Linear Blending) and vector mathematics formulated in the dual quaternion architecture. This guidance system effectively smoothed the motion produced by the controller but currently needs further work to better its performance at worst case initial pose errors.

Currently, the last remaining piece needed to develop a basic DQGNC system is an observer (state estimator) for navigational state estimation. Some dual quaternion extended Kalman filters (DQEKF) have been found in the literature but the NIFS intern is unfamiliar with estimation techniques and a study of them is needed before a DQEFK can be comfortably implemented.

In the future, once a full DQGNC system with control laws, guidance algorithms, and navigational estimators has been developed, a sister GNC architecture in real quaternion and vector needs to be either developed or borrowed from an existing simulation for comparison to its DQGNC counterpart. This comparison will then reveal where the advantages in DQGNC lie. Further upgrades can follow to increase the computational efficiency and to test DQGNC in other scenarios such as those with constraints and disturbances. Eventually, this system will be implemented into hardware, but this will likely be after the end of the summer NIFS internship.