NONLINEAR DUAL QUATERNION CONTROL OF SPACECRAFT-MANIPULATOR SYSTEMS.

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Abstract: On-orbit satellite servicing (OSS) holds the promise to refuel, maintain, upgrade, and repair existing spacecraft, enable space construction, and help actively remove orbital debris [1]. Although some OSS missions may only need a spacecraft-manipulator system (SCMS) to stabilize the relative kinematics between itself and the target satellite, future missions may require multi-objective maneuvering such as requiring a single point of contact between two satellites at the end-effector, while also controlling the spacecraft-base so as to maintain a line-of-sight with Earth for communication purposes. In such cases, simultaneous precise end-effector control of the maneuvering satellite and spacecraft-base is required. However, the coordinated control of a multibody, multi-control-input SCMS remains a challenging problem.

Unlike the traditional, fully decoupled, 3-degree-of-freedom (DOF) relative attitude [2], the control problem of a spacecraft with manipulator(s) add an additional N-DOFs to the system, which is challenging to solve using existing control methods [3], including the introduction of both kinematic and dynamic singularities during controlled end-effector maneuvers [4]. Such singularities can lead to unbounded joint velocities and control inputs. Typical approaches to tackle these challenges inherent with (6+N)-DOF SCMS control problem is roughly divided into two categories: internal control and coordinated control.

In this paper, we consider results from the dual quaternion community to describe the kinematics of the combined translational and rotational motion of a single or multiple rigid bodies [5] in order to develop a multibody pose controller for both the end-effector and spacecraft-base during a multi-objective SCMS maneuver. Specifically, we propose a dual quaternion nonlinear feedback controller for coordinated control of the SCMS end-effector and spacecraft-base. The proposed control achieves asymptotically stable pose tracking for the end-effector and the spacecraft-base of an SCMS simultaneously, given the SCMS initially begins in a nonsingular configuration. The proposed control law additionally offers a simple solution to avoid system singularities, which may occur during the tracking maneuver, ensuring that an SCMS control inputs remain bounded.

The control law is realized using a dual quaternion Lyapunov-based analysis. The derived controller ensures that the relative poses and rates of the end-effector and the spacecraft-base simultaneously converge to two independent time-varying reference trajectories. An example of convergence of the relative end-effector pose, given by dual quaternion, $\boldsymbol{q}_{\mathrm{G/E}}$, (G – end-effector frame, E – reference frame), and relative dual rates, $\boldsymbol{\omega}_{\mathrm{G/E}}$, of a nonredundant RRRS SCMS (R – Revolute, S – spherical) is shown in Figure 1, where a visualization the entire tracked maneuver, including the convergence of the base, is shown in Figure 2.

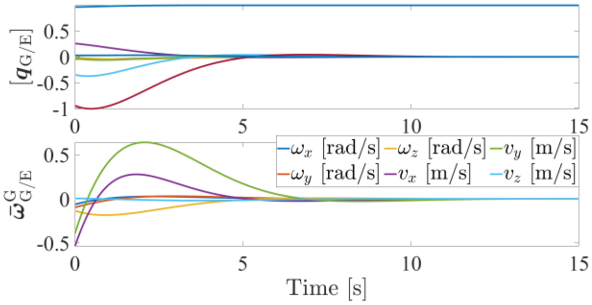

Figure 1. Relative dual quaternion, $\boldsymbol{q}_{\mathrm{G/E}}$, *and dual velocity,* $\boldsymbol{\omega}_{G/E}$, *of an RRRS SCMS end-effector with respect to* frame E *during tracking.*

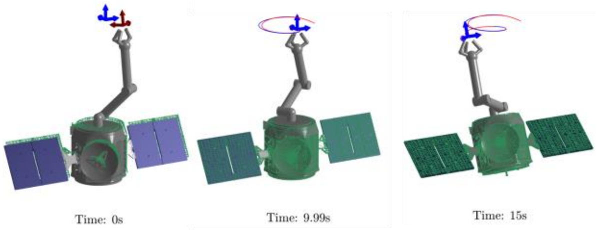

Figure 2. A tracking sequence of both the end-effector (show in red) and spacecraft-base to a time-varying references. The end-effector and base references are given in blue and green, respectively.

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