MASTER OF SCIENCE
IN
ASTRONAUTICAL ENGINEERING

DEVELOPMENT OF PRECISION POINTING CONTROLLERS WITH AND WITHOUT VIBRATION SUPPRESSION FOR THE NPS PRECISION POINTING HEXAPOD

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Satellite optical payloads demand better vibration control and finer precision pointing than ever before. Fortunately, the Stewart-Gough platform offers the potential of accomplishing both of these simultaneously.

Using the Precision Pointing Hexapod at NPS (a Stewart-Gough platform), several controllers for precision pointing, with and without vibration disturbances, were developed. Unlike the traditional means of pointing a hexapod, (i.e. sensing and controlling strut length to orient payload), this research used the payload orientation derived from payload mounted position sensors to determine orientation and provide feedback to the actuator controller. Small and large angle controllers were developed and evaluated for accuracy using static pointing and dynamic tracking tasks. The pointing controllers were then added to an Adaptive Disturbance Canceller and evaluated for pointing accuracy and vibration suppression performance given a single tone disturbance.

The results showed a static pointing accuracy of ±0.008° and a dynamic pointing accuracy ranging from ±0.05° to ±0.2°, depending on the size and speed of the circular trajectory. Vibration suppression down to the noise floor was achieved in all static orientations tested. As for dynamic circle-tracking performance, at least a 20 dB reduction in the fundamental disturbance was obtained without degradation in pointing accuracy.

KEYWORDS: Precision Pointing, Hexapod, Steward Platform, Vibration Suppression, Adaptive Disturbance Canceller

DEVELOPMENT AND CONTROL OF ROBOTIC ARMS FOR THE NAVAL POSTGRADUATE SCHOOL AUTONOMOUS DOCKING SIMULATOR (NPADS)

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This thesis encompasses the development of two robotic arms for integration onto the Naval Postgraduate School (NPS) Planar Autonomous Docking Simulator (NPADS) servicing vehicle. This research effort involved support structure design, fabrication, and construction, off-the-shelf motion control hardware integration, and control algorithm development and testing.

The NPADS system is being built as a test platform for spacecraft docking and capture mechanisms designed for autonomous rendezvous and servicing missions. As with the servicing vehicle, the robotic arms utilize a floatation system on an air-bearing granite table to provide a two-dimensional, drag-free environment. DC brushless servo motors serve as shoulder, elbow, and wrist joints allowing planar motion of the two-link arms. A National Instruments (NI) PXI computer and Motion Control card provide system processing and the software to hardware interface. The NI LabVIEW software suite enabled development

of manual control code and autonomous control subroutines compatible with the control software of the NPADS main body. A single, wrist-mounted CCD bullet camera provides visual target acquisition for the robotic arm control system.

Testing and analysis were completed in the NPS Satellite Servicing Laboratory on a table-based test harness to facilitate initial design iteration.

KEYWORDS: Motion Control, Robotic Arm, LabVIEW, Autonomous Docking, Satellite Simulator, DC Brushless Servo Motors

SPACECRAFT POWER BEAMING AND SOLAR CELL ANNEALING USING HIGH-ENERGY LASERS

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Satellite lifetime is often limited by degradation of the electrical power subsystem--radiation-damaged solar arrays and failed batteries. Being able to beam power from terrestrial sites could alleviate this limitation, extending the lifetime of billions of dollars of satellite assets, as well as providing additional energy for electric propulsion that can be used for stationkeeping and orbital changes. In addition, laboratory research at the Naval Postgraduate School (NPS) has shown the potential to anneal damaged solar cells using lasers. This thesis describes that research, preliminary work performed lasing a representative solar panel array, and a proposed on-orbit experiment to demonstrate the relevant concepts by lasing PANSAT, an NPS-built and operated spacecraft.

The preliminary work done at Maui involved lasing a PANSAT silicon photovoltaic array using a 975 nm Yb:YAG source at output power levels of 7 W, 14 W and 21 W. These results matched those obtained under near-AM0 conditions atop Mount Haleakala (for the 7 W case) and extrapolated to match predicted output levels. Enough data points were collected at each power level to generate an I-V curve for the panel, identifying the open circuit voltage, short circuit current, and maximum power points. The efficiency of the panel varied from 13.1% (as expected for monochromatic light) at 7W to 11.3% at 21 W due to uniform heating of the cells. These results represent a “ground truth” baseline from which further research can continue.

KEYWORDS: Laser, Solar Cell, Photovoltaics, Power Beaming, Annealing, Wireless Power Transmission, Electric Propulsion, PANSAT

DESIGN OF OPTIMAL CYCLERS USING SOLAR SAILS

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Ongoing interest in establishing a base on Mars has spurred a need for regular and repeated visits to the red planet using a cycling shuttle to transport supplies, equipment and to retrieve surface samples. This thesis presents an approach to designing an optimal heliocentric cycling orbit, or cycler, using solar sails. Results show that solar sails can be used to significantly reduce V_∞s at Mars and Earth. For example, using a reasonably high performance solar sail, a $V_\infty|_{Mars} = 2.5$ km/s is possible at every synodic period using a two-dimensional orbit model. Lower performance sails were also modeled resulting in paths that behaved more like a ballistic Aldrin cycler with higher V_∞s. Double rendezvous missions were explored where the

spacecraft must match the velocities of both Earth and Mars, offering promising trajectories for Mars sample return missions. The solutions to these missions, although not necessarily cyclers, show that using a sail to rendezvous with and remain near Mars for an optimal amount of time will minimize the total transit time between Earth and Mars. General-purpose dynamic optimization software, DIDO, is used to solve the optimal control problem using a pseudospectral method using both two- and three-dimensional elliptic orbit models.

KEYWORDS: Cycler Trajectory, Solar Sail, Optimal Design, DIDO, Mars Mission, Trajectory Design, Cycling Orbits

INITIATOR DIFFRACTION LIMITS FOR PULSE DETONATION ENGINE OPERATION

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Operational characteristics of a valveless pulse detonation engine system are being characterized by both experimental and computational efforts. The detonation diffraction process from a small "initiator" combustor to a larger diameter main combustor in a continuous airflow configuration was evaluated during multi-cycle operation of a pulse detonation engine. The multi-cycle detonation experiments were performed on an axisymetric engine geometry operating on both ethylene and propane fuel/air mixtures. The new design explored the effect of forward relief area on performance and its ability to isolate the detonation products from the incoming air flow during cyclic operation.

The use of a small fuel-oxygen initiator to initiate a fuel/air detonation in a larger main combustor has been achieved and has demonstrated the benefit of generating an overdriven detonation condition near the diffraction plane for enhanced transmission to a larger combustor. Mach reflections have been observed on the outer wall downstream of the diffraction plane for the two-dimensional geometry and appear to be the primary re-initiation mechanisms for the re-established fuel-air detonations for this geometry. Multi-cycle tests have successfully evaluated initiator/main combustor diameter ratios of up to 1.58 and are expected to continue through 2.0.

KEYWORDS: Pulse Detonation Engine, Detonation, Valveless, Space Propulsion, Hydrocarbon Fuels