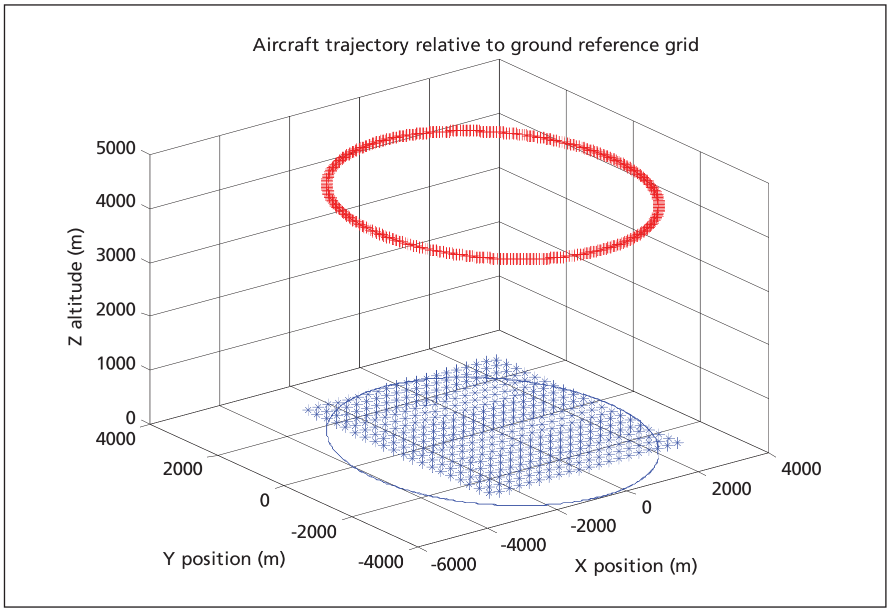


Aircraft Trajectory relative to ground reference gid.

The new georegistration approach was validated by computer simulation based on an aircraft flying at a speed of 70 m/s in a 3-km radius circle at an altitude of 15,000 ft (≈4,600 m), using a camera pointed at the ground toward the center of the circle. Results from using the nonlinear estimation algorithm, in combination with GPS and camera images taken once per second, indicate that after 20 minutes of operation, real-time georegistration errors are reduced to values of less than 2 m, 1 sigma, on the ground.

The new method is very modular and cleanly separates computer vision functions from optimal estimation functions. This allows the vision and estimation functions to be developed separately, and leverages the power of modern estimation theory to fuse information in an optimal manner. Heuristics are avoided, which are generally suboptimal, as are other methods that require human-in-the-loop intervention, ad hoc parameter weightings, and awkward stitching together of various types of data.

The work is applicable to any scientific or engineering application that requires finding the geolocation of specific objects seen in a sequence of camera images. For example, in a surveying application, the precise location and height of a mountain peak can be determined by having an airplane take aerial images while circling around it.

This work was done by David S. Bayard and Curtis W. Padgett of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47255.

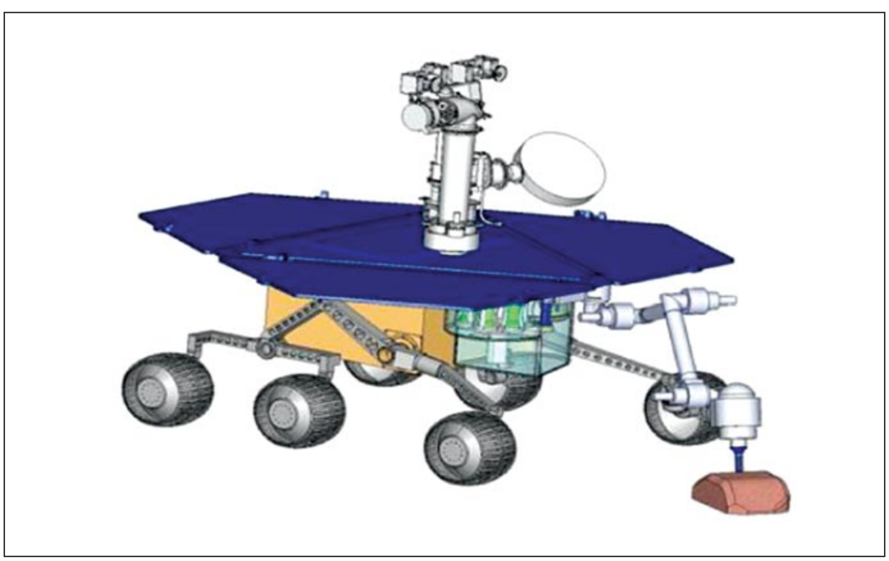
Optimal Force Control of Vibro-Impact Systems for Autonomous Drilling Applications

A method is investigated how to maximize energy transfer to tools used in drilling, and can be applied to regular power tools.

NASA's Jet Propulsion Laboratory, Pasadena, California

The need to maintain optimal energy efficiency is critical during the drilling operations performed on future and current planetary rover missions (see figure). Specifically, this innovation seeks to solve the following problem. Given a spring-loaded percussive drill driven by a voice-coil motor, one needs to determine the optimal input voltage waveform (periodic function) and the optimal hammering period that minimizes the dissipated energy, while ensuring that the hammer-to-rock impacts are made with sufficient (user-defined) impact velocity (or impact energy).

To solve this problem, it was first observed that when voice-coil-actuated percussive drills are driven at high power, it is of paramount importance to ensure that the electrical current of the device remains in phase with the velocity of the



Planetary Rover equipped with a rotary percussive drill.

hammer. Otherwise, negative work is performed and the drill experiences a loss of performance (i.e., reduced impact energy) and an increase in Joule heating (i.e., reduction in energy efficiency). This observation has motivated many drilling products to incorporate the standard bang-bang control approach for driving their percussive drills. However, the bang-bang control approach is significantly less efficient than the optimal energy-efficient control approach solved herein.

To obtain this solution, the standard tools of classical optimal control theory were applied. It is worth noting that these tools inherently require the solution of a two-point boundary value problem (TPBVP), i.e., a system of differential equations where half the equations have unknown boundary conditions. Typically, the TPBVP is impossible to solve analytically for high-dimensional dynamic systems. However, for the case of the spring-loaded vibro-impactor, this approach yields the exact optimal control solution as the sum of four analytic functions whose coefficients are determined using a simple, easy-to-implement algorithm. Once the optimal control waveform is determined, it can be used optimally in the context of both open-loop and closed-loop control modes (using standard real-time control hardware).

Future NASA *in situ* exploration missions increasingly require extensive drilling and coring procedures that stress the demand for more energy efficient methods to accomplish these tasks. For example, when rover-based autonomous drills are controlled non-optimally for long periods of time, the energy loss can grow at a rate that cannot be sustained by the rover's internal energy supply. Motorized percussive units can be especially energy-draining (when controlled non-optimally), making this technology especially relevant to this type of future NASA work.

This work was done by Jack B. Aldrich and Avi B. Okon of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48467

Low-Cost Telemetry System for Small/Micro Satellites

Marshall Space Flight Center, Alabama

A Software Defined Radio (SDR) concept uses a minimum amount of analog/radio frequency components to up/downconvert the RF signal to/from a digital format. Once in the digital domain, all other processing (filtering, modulation, demodulation, etc.) is done in software. The project will leverage existing designs and enhance capabilities in the commercial sector to provide a path to a radiation-hardened SDR transponder.

The SDR transponder would incorporate baseline technologies dealing with improved Forward Error Correcting (FEC) codes to be deployed to all Near Earth Network (NEN) ground stations. By incorporating this FEC, at least a tenfold increase in data throughput can be achieved.

A family of transponder products can be implemented using common platform architecture, allowing new products to be more quickly introduced into the market. Software can be reused across products, reducing software/hardware costs dramatically. New features and capabilities, such as encoding and decoding algorithms, filters, and bit synchronizers, can be added to the existing infrastructure without requiring major new capital expenditures, allowing implementation of advanced features in the communication systems.

As new telecommunication technologies emerge, incorporating them into the SDR fabric will be easily accomplished with little or no requirements for new hardware. There are no preferred flight platforms for the SDR technology, so it can be used on any type of orbital or sub-orbital platform, all within a fully radiation hardened design.

This work was done by William Sims and Kosta Varnavas of Marshall Space Flight Center.

This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32871-1.

Operator Interface and Control Software for the Reconfigurable Surface System Tri-ATHLETE

The capability of future exploration missions may be greatly extended for a small additional cost.

NASA's Jet Propulsion Laboratory, Pasadena, California

Graphical operator interface methods have been developed for modular, reconfigurable articulated surface systems in general, and a specific instantiation thereof for JPL's Tri-ATHLETE. The All-Terrain Hex-Limbed Extra-Terrestrial Explorer Robot (ATHLETE) has six limbs with six kinematic degrees of freedom each (see figure).

The core advancement of this work was the development of a novel set of algorithms for dynamically maintaining a reduced coordinate model of any connected assembly of robot modules. The kinematics of individual modules are first modeled using a catalog of 12 standard 3D robot joints (this modeling step needs to be done only once). Then, individual modules can be assembled into any closed- or open-chain topology. The system automatically maintains a spanning tree of the overall configuration, which ensures both efficiency and accuracy of the on-screen representation.

Until now, JPL has used generic CAD (computer-aided design), simulation, and animation tools as a substitute for a