Frequency-Modulated, Continuous-Wave Laser Ranging Using Photon-Counting Detectors

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Optical ranging is a problem of estimating the round-trip flight time of a phase- or amplitude-modulated optical beam that reflects off of a target. Frequency-modulated, continuous-wave (FMCW) ranging systems obtain this estimate by performing an interferometric measurement between a local frequency-modulated laser beam and a delayed copy returning from the target. The range estimate is formed by mixing the target-return field with the local reference field on a beamsplitter and detecting the resultant beat modulation. In conventional FMCW ranging, the source modulation is linear in instantaneous frequency, the reference-arm field has many more photons than the target-return field, and the time-of-flight estimate is generated by balanced difference-detection of the beamsplitter output, followed by a frequency-domain peak search.

This work focused on determining the maximum-likelihood (ML) estimation algorithm when continuous-time photon-counting detectors are used. It is founded on a rigorous statistical characterization of the (random) photoelectron emission times as a function of the incident optical field, including the deleterious effects caused by dark current and dead time. These statistics enable derivation of the Cramér-Rao lower bound (CRB) on the accuracy of FMCW ranging, and derivation of the ML estimator, whose performance approaches this bound at high photon flux.

The estimation algorithm was developed, and its optimality properties were shown in simulation. Experimental data show that it performs better than the conventional estimation algorithms used. The demonstrated improvement is a factor of 1.414 over frequency-domain-based estimation.

If the target interrogating photons and the local reference field photons are costed equally, the optimal allocation of photons between these two arms is to have them equally distributed. This is different than the state of the art, in which the local field is stronger than the target return. The optimal processing of the photocurrent processes at the outputs of the two detectors is to perform log-matched filtering followed by a summation and peak detection. This implies that neither difference detection, nor Fourier-domain peak detection, which are the staples of the state-of-the-art systems, is optimal when a weak local oscillator is employed.

This work was done by Baris I. Erkmen of Caltech, and Zeb W. Barber and Jason Dahl of Montana State University for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-48866

Calculation of Operations Efficiency Factors for Mars Surface Missions

Several modeling methods are examined.

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For planning of Mars surface missions, to be operated on a sol-by-sol basis by a team on Earth (where a "sol" is a Martian day), activities are described in terms of "sol types" that are strung together to build a surface mission scenario. Some sol types require ground decisions based on a previous sol's results to feed into the activity planning ("ground in the loop"), while others do not. Due to the differences in duration between Earth days and Mars sols, for a given Mars local solar time, the corresponding Earth time "walks" relative to the corresponding times on the prior sol/day. In particular, even if a communication window has a fixed Mars local solar time, the Earth time for that window will be approximately 40 minutes later each succeeding day. Further complexity is added for non-Mars synchronous communication relay assets, and when there are multiple control centers in different Earth time zones.

The solution is the development of "ops efficiency factors" that reflect the efficiency of a given operations configuration (how many and location of control centers, types of communication windows, synchronous or non-synchronous nature of relay assets, sol types, more-or-less sustainable operations schedule choices) against a theoretical "optimal" operations configuration for the mission being studied. These factors are then incorporated into scenario models in order to determine the surface duration (and therefore minimum spacecraft surface lifetime) required to fulfill scenario objectives. The resulting model is used to perform "what-if" analyses for variations in scenario objectives. The ops efficiency factor is the ratio of the figure of merit for a given operations factor to the figure of merit for the theoretical optimal configuration.

The current implementation is a pair of models in Excel. The first represents a ground operations schedule for 500 sols in each operations configuration for the mission being studied (500 sols was chosen as being a long enough time to capture variations in relay asset interactions, Earth/Mars time phasing, and seasonal variations in holidays). This model is used to estimate the ops efficiency factor for each operations configuration.

The second model in a separate Excel spreadsheet is a scenario model, which uses the sol types to rack up the total number of "scenario sols" for that scenario (in other words, the ideal number of sols it would take to perform the scenario objectives). Then, the number of sols requiring ground in the loop is calculated based on the soil types contained in the given scenario. Next, the scenario contains a description of what sequence of operations configurations is used, for how many days each, and this is used with the corresponding ops efficiency factors for each configuration to calculate the "ops duration" corresponding to that scenario. Finally, a margin is applied to determine the minimum surface lifetime required for that scenario.

Typically, this level of analysis has not been performed until much later in the mission, and has not been able to influence mission design. Further, the notion of moving to sustainable operations during Prime Mission — and the effect that that move would have on surface mission productivity and mission objective choices — has not been encountered until the most recent rover missions (MSL and Mars 2018).

This work was done by Sharon L. Layback of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48262

GPU Lossless Hyperspectral Data Compression System

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Hyperspectral imaging systems onboard aircraft or spacecraft can acquire large amounts of data, putting a strain on limited downlink and storage resources. Onboard data compression can mitigate this problem but may require a system capable of a high throughput. In order to achieve a high throughput with a software compressor, a graphics processing unit (GPU) implementation of a compressor was developed targeting the current state-of-the-art GPUs from NVIDIA®.

The implementation is based on the fast lossless (FL) compression algorithm reported in "Fast Lossless Compression of Multispectral-Image Data" (NPO-42517), *NASA Tech Briefs*, Vol. 30, No. 8 (August 2006), page 26, which operates on hyperspectral data and achieves excellent compression performance while having low complexity. The FL compressor uses an adaptive filtering method and achieves state-of-the-art performance in both compression effectiveness and low complexity. The new Consultative Committee for Space Data Systems (CCSDS) Standard for Lossless Multispectral & Hyperspectral image compression (CCSDS 123) is based on the FL compressor. The software makes use of the highly-parallel processing capability of GPUs to achieve a throughput at least six times higher than that of a software implementation running on a single-core CPU. This implementation provides a practical real-time solution for compression of data from airborne hyperspectral instruments.

This work was done by Nazeeh I. Aranki, Didier Keymeulen, Aaron B. Kiely, and Matthew A. Klimesh of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

The software used in this innovation is available for commercial licensing. Please contact Dan Broderick at Daniel.F.Broderick@jpl.nasa.gov. Refer to NPO-48571.

Robust, Optimal Subsonic Airfoil Shapes

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A method has been developed to create an airfoil robust enough to operate satisfactorily in different environments. This method determines a robust, optimal, subsonic airfoil shape, beginning with an arbitrary initial airfoil shape, and imposes the necessary constraints on the design. Also, this method is flexible and extendible to a larger class of requirements and changes in constraints imposed.

In one embodiment, process steps include providing a specification of a desired pressure value at each of a sequence of selected locations on the surface of a turbine airfoil; providing an initial airfoil shape; providing a statement of at least one constraint to which a final airfoil shape must conform; using computational fluid dynamics (CFD) to estimate a pressure value at each of the selected perimeter locations for the initial airfoil shape; using CFD to determine the pressure distribution for the airfoil shapes that are small perturbations to the initial airfoil shape; and using an estimation method, such as a neural network, a support vector machine, or a combination thereof, to construct a response surface that models the pressure distribution as a function of the airfoil shape using the CFD data. Other process steps include using an optimization algorithm to search the response surface for the airfoil shape having the required pressure distribution, and providing at least one of an alphanumeric description and a graphical description of the modified airfoil shape.

Constraints may be drawn from the following group, or may be one or more other suitable constraints: vortex shedding strength from the trailing edge of the airfoil is no greater than a selected threshold value; a difference between any resonant frequency of the airfoil and the vortex shedding frequency is at least equal to a threshold frequency difference; mass of the airfoil is no larger than a threshold mass value; and pressure value at each of a sequence of selected locations along the surface of the airfoil differs from a corresponding reference pressure value by no more than a threshold pressure difference value.

This work was done by Man Mohan Rai of Ames Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at 1-855-NASA-BIZ (1-855-6272-249). Refer to ARC-14586-2