Information Technology

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.

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