

veyed from the transmitting end to the receiving end of a radio or optical communication channel is a  $K$ -bit vector  $\mathbf{u}$ . This vector is encoded by an  $(N, K)$  binary error-correcting code, producing an  $N$ -bit vector  $\mathbf{a}$ . In turn, the vector  $\mathbf{a}$  is subdivided into blocks of  $m = \log_2(M)$  bits and each such block is mapped to an  $M$ -ary PPM symbol. The resultant coding/modulation scheme can be regarded as equivalent to a nonlinear binary code. The binary vector of PPM symbols,  $\mathbf{x}$  is transmitted over a Poisson channel, such that there is obtained, at the receiver, a Poisson-distributed photon count characterized by a mean background count  $n_b$  during no-pulse time slots and a mean signal-plus-background count of  $n_s + n_b$  during a pulse time slot.

In the receiver, demodulation of the signal is effected in an iterative soft decoding process that involves considera-

tion of relationships among photon counts and conditional likelihoods of  $m$ -bit vectors of coded bits. Inasmuch as the likelihoods of all the  $m$ -bit vectors of coded bits mapping to the same PPM symbol are correlated, the best performance is obtained when the joint  $m$ -bit conditional likelihoods are utilized. Unfortunately, the complexity of decoding, measured in the number of operations per bit, grows exponentially with  $m$ , and can thus become prohibitively expensive for large PPM orders. For a system required to handle multiple PPM orders, the cost is even higher because it is necessary to have separate decoding hardware for each order. This concludes the prerequisite background information.

In the present algorithm, the decoding process as described above is modified by, among other things, introduction of an  $l$ -

bit marginalizer subalgorithm. The term “ $l$ -bit marginalizer” signifies that instead of  $m$ -bit conditional likelihoods, the decoder computes  $l$ -bit conditional likelihoods, where  $l$  is fixed. Fixing  $l$ , regardless of the value of  $m$ , makes it possible to use a single hardware implementation for any PPM order. One could minimize the decoding complexity and obtain an especially simple design by fixing  $l$  at 1, but this would entail some loss of performance. An intermediate solution is to fix  $l$  at some value, greater than 1, that may be less than or greater than  $m$ . This solution makes it possible to obtain the desired flexibility to handle any PPM order while compromising between complexity and loss of performance.

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## Algorithm for Stabilizing a POD-Based Dynamical System

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This algorithm provides a new way to improve the accuracy and asymptotic behavior of a low-dimensional system based on the proper orthogonal decomposition (POD). Given a data set representing the evolution of a system of partial differential equations (PDEs), such as the Navier-Stokes equations for incompressible flow, one may obtain a low-dimensional model in the form of ordinary differential equations (ODEs) that should model the dynamics of the flow. Temporal sampling of the direct numerical simulation of the PDEs produces a

spatial time series. The POD extracts the temporal and spatial eigenfunctions of this data set. Truncated to retain only the most energetic modes followed by Galerkin projection of these modes onto the PDEs obtains a dynamical system of ordinary differential equations for the time-dependent behavior of the flow.

In practice, the steps leading to this system of ODEs entail numerically computing first-order derivatives of the mean data field and the eigenfunctions, and the computation of many inner products. This is far from a perfect

process, and often results in the lack of long-term stability of the system and incorrect asymptotic behavior of the model. This algorithm describes a new stabilization method that utilizes the temporal eigenfunctions to derive correction terms for the coefficients of the dynamical system to significantly reduce these errors.

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## Mission Reliability Estimation for Repairable Robot Teams

**An analytical model demonstrates autonomous and intelligent control systems capable of operating distributed, multi-planetary surface vehicles for scouting or construction.**

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A mission reliability estimation method has been designed to translate mission requirements into choices of robot modules in order to configure a multi-robot team to have high reliability at minimal cost. In order to build cost-effective robot teams for long-term missions, one must be able to compare alternative design paradigms in a principled way by comparing the reliability of different robot models and robot team configura-

tions. Core modules have been created including: a probabilistic module with reliability-cost characteristics, a method for combining the characteristics of multiple modules to determine an overall reliability-cost characteristic, and a method for the generation of legitimate module combinations based on mission specifications and the selection of the best of the resulting combinations from a cost-reliability standpoint.

The developed methodology can be used to predict the probability of a mission being completed, given information about the components used to build the robots, as well as information about the mission tasks. In the research for this innovation, sample robot missions were examined and compared to the performance of robot teams with different numbers of robots and different numbers of spare components.

Data that a mission designer would need was factored in, such as whether it would be better to have a spare robot versus an equivalent number of spare parts, or if mission cost can be reduced while maintaining reliability using spares.

This analytical model was applied to an example robot mission, examining the cost-reliability tradeoffs among different team configurations. Particularly scrutinized were teams using either redun-

dancy (spare robots) or repairability (spare components). Using conservative estimates of the cost-reliability relationship, results show that it is possible to significantly reduce the cost of a robotic mission by using cheaper, lower-reliability components and providing spares. This suggests that the current design paradigm of building a minimal number of highly robust robots may not be the best way to design robots for extended missions.

*This work was done by Ashitey Trebi-Olennu of Caltech and John Dolan and Stephen Stancliff of Carnegie Mellon University for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-44825.*