the specific information symbols are chosen uniform randomly from the message block. Finally, the selected information symbols are XORed to form the code symbol. The Prioritized LT code construction includes an additional restriction that code symbols formed by a relatively small number of XORed information symbols select some of these information symbols from the pool of high-priority data. Once high-priority data are fully covered, encoding continues with the conventional LT approach where code symbols are generated by selecting information symbols from the entire message block including all different priorities. Therefore, if code symbols derived from high-priority data experience an unusual high number of erasures, Prioritized LT codes can still reliably recover both high- and low-priority data. This hybrid approach decides not only "how to encode" but also "what to encode" to achieve UEP. Another advantage of the priority encoding process is that the majority of high-priority data can be decoded sooner since only a small number of code symbols are required to reconstruct high-priority data. This approach increases the likelihood that high-priority data is decoded first over low-priority data.

The Prioritized LT code scheme achieves an improvement in high-priority data decoding performance as well as overall information recovery without penalizing the decoding of low-priority data, assuming high-priority data is no more than half of a message block. The cost is in the additional complexity required in the encoder. If extra computation resource is available at the transmitter, image, voice, and video transmission quality in terrestrial and space communications can benefit from accurate use of redundancy in protecting data with varying priorities.

This work was done by Simon S. Woo and Michael K. Cheng of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-46653

Fast Image Texture Classification Using Decision Trees

The algorithms used can be applied to robotics, image retrieval for Web searching, and computer vision for electronic devices.

NASA's Jet Propulsion Laboratory, Pasadena, California

Texture analysis would permit improved autonomous, onboard science data interpretation for adaptive navigation, sampling, and downlink decisions. These analyses would assist with terrain analysis and instrument placement in both macroscopic and microscopic image data products. Unfortunately, most state-of-the-art texture analysis demands computationally expensive convolutions of filters involving many floating-point operations. This makes them infeasible for radiation-hardened computers and spaceflight hardware.

A new method approximates traditional texture classification of each image pixel with a fast decision-tree classifier. The classifier uses image features derived from simple filtering operations involving integer arithmetic. The texture analysis method is therefore amenable to implementation on FPGA (field-programmable gate array) hardware.

Image features based on the "integral image" transform produce descriptive and efficient texture descriptors. Training the decision tree on a set of training data yields a classification scheme that produces reasonable approximations of optimal "texton" analysis at a fraction of the computational cost. A decision-tree learning algorithm employing the traditional k-means criterion of inter-cluster variance is used to learn tree structure from training data. The result is an efficient and accurate summary of surface morphology in images.

This work is an evolutionary advance that unites several previous algorithms (k-means clustering, integral images, decision trees) and applies them to a new problem domain (morphology analysis for autonomous science during remote exploration). Advantages include order-of-magnitude improvements in runtime, feasibility for FPGA hardware, and significant improvements in texture classification accuracy.

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Constraint Embedding Technique for Multibody System Dynamics

This approach is applicable to multibody dynamics modeling of vehicles and robots.

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Multibody dynamics play a critical role in simulation testbeds for space missions. There has been a considerable interest in the development of efficient computational algorithms for solving the dynamics of multibody systems. Mass matrix factorization and inversion techniques and the $O(N)$ class of forward dynamics algorithms developed using a spatial operator algebra stand out as important breakthrough on this front. Techniques such as these provide the efficient algorithms and methods for the application and implementation of such multibody dynamics models. However, these methods are limited only to tree-topology multibody systems.

Closed-chain topology systems require different techniques that are not as efficient or as broad as those for tree-topolgy systems. The closed-chain forward dynamics approach consists of treating the closed-chain topology as a tree-topology system subject to additional closure constraints. The resulting forward dynamics solution consists of: (a) ignoring the closure constraints and using the $O(N)$ algorithm to solve for the "free" unconstrained accelerations for the system; (b) using the tree-topology solution to compute a correction force to enforce the closure constraints; and (c) correcting the unconstrained accelerations with correction accelerations resulting from the correction forces.

This constraint-embedding technique shows how to use direct embedding to eliminate local closure-loops in the system and effectively convert the system back to a tree-topology system. At this point, standard tree-topology techniques can be brought to bear on the problem. The approach uses a spatial operator algebra approach to formulating the equations of motion. The operators are block-partitioned around the local body subgroups to convert them into aggregate bodies. Mass matrix operator factorization and inversion techniques are applied to the reformulated tree-topology system. Thus in essence, the new technique allows conversion of a system with closure-constraints into an equivalent tree-topology system, and thus allows one to take advantage of the host of techniques available to the latter class of systems.

This technology is highly suitable for the class of multibody systems where the closure-constraints are local, i.e., where they are confined to small groupings of bodies within the system. Important examples of such local closure-constraints are constraints associated with four-bar linkages, geared motors, differential suspensions, etc. One can eliminate these closure-constraints and convert the system into a tree-topology system by embedding the constraints directly into the system dynamics and effectively replacing the body groupings with virtual aggregate bodies. Once eliminated, one can apply the well-known results and algorithms for tree-topology systems to solve the dynamics of such closed-chain system.

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Improved Systematic Pointing Error Model for the DSN Antennas

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New pointing models have been developed for large reflector antennas whose construction is founded on elevation over azimuth mount. At JPL, the new models were applied to the Deep Space Network (DSN) 34-meter antenna's subnet for corrections of their systematic pointing errors; it achieved significant improvement in performance at Ka-band (32-GHz) and X-band (8.4-GHz). The new models provide pointing improvements relative to the traditional models by a factor of two to three, which translate to approximately 3-dB performance improvement at Ka-band. For radio science experiments where blind pointing performance is critical, the new innovation provides a new enabling technology.

The model extends the traditional physical models with higher-order mathematical terms, thereby increasing the resolution of the model for a better fit to the underlying systematic imperfections that are the cause of antenna pointing errors. The philosophy of the traditional model was that all mathematical terms in the model must be traced to a physical phenomenon causing antenna pointing errors. The traditional physical terms are: antenna axis tilts, gravitational flexure, azimuth collimation, azimuth encoder fixed offset, azimuth and elevation skew, elevation encoder fixed offset, residual refraction, azimuth encoder scale error, and antenna pointing de-rotation terms for beam waveguide (BWG) antennas.

Besides the addition of spherical harmonics terms, the new models differ from the traditional ones in that the coefficients for the cross-elevation and elevation corrections are completely independent and may be different, while in the traditional model, some of the terms are identical. In addition, the new software allows for all-sky or mission-specific model development, and can utilize the previously used model as an *a priori* estimate for the development of the updated models.

This work was done by David J. Rochblatt, Philip M. Withington, and Paul H. Richter of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-46852

Observability and Estimation of Distributed Space Systems via Local Information-Exchange Networks

An agreement protocol is used as a mechanism for observing formation states from local measurements.

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Spacecraft formation flying involves the coordination of states among multiple spacecraft through relative sensing, inter-spacecraft communication, and control. Most existing formation-flying estimation algorithms can only be supported via highly centralized, all-to-all, static relative sensing. New algorithms are proposed that are scalable, modular, and robust to variations in the topology and link characteristics of the formation exchange network. These distributed algorithms rely on a local information exchange network, relaxing the assumptions on existing algorithms.

Distributed space systems rely on a signal transmission network among multiple spacecraft for their operation. Control and coordination among multiple spacecraft in a formation is facilitated via a network of relative sensing and inter-spacecraft communications. Guidance, navigation, and control rely on the sensing network. This network becomes