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.

This work was done by Abhinandan Jain and Rudranarayan Mukherjee of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-46950

Improved Systematic Pointing Error Model for the DSN Antennas

NASA's Jet Propulsion Laboratory, Pasadena, California

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.

NASA's Jet Propulsion Laboratory, Pasadena, California

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