











TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

-  **Technology Focus**
-  **Electronics/Computers**
-  **Software**
-  **Materials**
-  **Mechanics/Machinery**
-  **Manufacturing**
-  **Bio-Medical**
-  **Physical Sciences**
-  **Information Sciences**
-  **Books and Reports**

INTRODUCTION

Tech Briefs are short announcements of innovations originating from research and development activities of the National Aeronautics and Space Administration. They emphasize information considered likely to be transferable across industrial, regional, or disciplinary lines and are issued to encourage commercial application.

Additional Information on NASA Tech Briefs and TSPs

Additional information announced herein may be obtained from the NASA Technical Reports Server: <http://ntrs.nasa.gov>.

Please reference the control numbers appearing at the end of each Tech Brief. Information on NASA's Innovative Partnerships Program (IPP), its documents, and services is available on the World Wide Web at <http://www.ipp.nasa.gov>.

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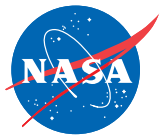
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SNE Industrial Fieldbus Interface

The purpose is to enable a smart sensor to communicate health and status information to other devices.

John F. Kennedy Space Center, Florida

Programmable logic controllers (PLCs) have very limited diagnostic and no prognostic capabilities, while current smart sensor designs do not have the capability to communicate over Fieldbus networks. The aim is to interface smart sensors with PLCs so that health and status information, such as failure mode identification and measurement tolerance, can be communicated via an industrial Fieldbus such as ControlNet.

The SNE Industrial Fieldbus Interface (SIFI) is an embedded device that acts as a communication module in a networked smart sensor. The purpose is to enable a smart sensor to communicate health and status information to other devices, such as PLCs, via an industrial Fieldbus networking protocol. The SNE (Smart Network Element) is attached to a commercial off-the-shelf Anybus-S interface module through the SIFI. Numerous Anybus-S modules are available,

each one designed to interface with a specific Fieldbus. Development of the SIFI focused on communications using the ControlNet protocol, but any of the Anybus-S modules can be used.

The SIFI communicates with the Anybus module via a data buffer and mailbox system on the Anybus module, and supplies power to the module. The Anybus module transmits and receives data on the Fieldbus using the proper protocol. The SIFI is intended to be connected to other existing SNE modules in order to monitor the health and status of a transducer. The SIFI can also monitor aspects of its own health using an on-board watchdog timer and voltage monitors. The SIFI also has the hardware to drive a touchscreen LCD (liquid crystal display) unit for manual configuration and status monitoring.

The SIFI communicates with the Anybus module via a data buffer and

mailbox system located on the Anybus module. The SIFI also has headers to connect with the digital and analog SNE modules. A microcontroller is used to control communications with the Anybus module. The microcontroller is capable of processing data either received from or to be transferred to the Anybus module.

Communication is via a parallel interface. The microcontroller is also connected to a real-time clock and 128 kB of external non-volatile FRAM (ferroelectric RAM) memory. For internal diagnostics, the microcontroller is connected to a watchdog timer and is capable of monitoring the levels of the ± 12 V and ± 10 V voltages.

This work was done by Angel Lucena of Kennedy Space Center; and Matthew Raines, Rebecca Oostdyk, and Carlos Mata of ASRC Aerospace Corporation. Further information is contained in a TSP (see page 1). KSC-13425

Composite Thermal Switch

This switch can be incorporated in portable electronic devices like cell phones, PDAs, laptop computers, and battery-powered electric vehicles.

John H. Glenn Research Center, Cleveland, Ohio

Lithium primary and lithium ion secondary batteries provide high specific energy and energy density. The use of these batteries also helps to reduce launch weight. Both primary and secondary cells can be packaged as high-rate cells, which can present a threat to crew and equipment in the event of external or internal short circuits. Overheating of the cell interior from high current flows induced by short circuits can result in exothermic reactions in lithium primary cells and fully charged lithium ion secondary cells. Venting of the cell case, ejection of cell components, and fire have been reported in both types of cells, resulting from abuse,

cell imperfections, or faulty electronic control design.

A switch has been developed that consists of a thin layer of composite material made from nanoscale particles of nickel and Teflon that conducts electrons at room temperature and switches to an insulator at an elevated temperature, thus interrupting current flow to prevent thermal runaway caused by internal short circuits. The material is placed within the cell, as a thin layer incorporated within the anode and/or the cathode, to control excess currents from metal-to-metal or metal-to-carbon shorts that might result from cell crush or a manufacturing defect. The safety of high-rate cells is thus

improved, preventing serious injury to personnel and sensitive equipment located near the battery. The use of recently available nanoscale particles of nickel and Teflon permits an improved, homogeneous material with the potential to be fine-tuned to a unique switch temperature, sufficiently below the onset of a catastrophic chemical reaction. The smaller particles also permit the formation of a thinner control film layer (< 50 μm), which can be incorporated into commercial high-rate lithium primary and secondary cells.

The innovation permits incorporation in current lithium and lithium-ion cell designs with a minimal impact on

cell weight and volume. The composite thermal switch (CTS™) coating can be incorporated in either the anode or cathode or both. The coating can be applied in a variety of different processes that permits incorporation in the cell and electrode manufacturing processes. The CTS responds quickly and halts

current flow in the hottest parts of the cell first. The coating can be applied to metal foil and supplied as a cell component onto which the active electrode materials are coated.

This work was done by Robert McDonald, Shelly Brawn, Katherine Harrison, Shannon O'Toole, and Michael Moeller of Giner, Inc. for

Glenn 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 NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18767-1.

XMOS XC-2 Development Board for Mechanical Control and Data Collection

NASA's Jet Propulsion Laboratory, Pasadena, California

The scanning microwave limb sounder (SMLS) will use technological improvements in low-noise mixers to provide precise data on the Earth's atmospheric composition with high spatial resolution. This project focuses on the design and implementation of a real-time control system needed for airborne engineering tests of the SMLS. The system must coordinate the actuation of optical components using four motors with encoder readback, while collecting synchronized telemetric data from a GPS receiver and 3-axis gyrometric system. A graphical user interface for testing the control system was also designed using Python.

Although the system could have been implemented with an FPGA (field-programmable gate array)-based setup, a processor development kit manufactured by XMOS was chosen. The

XMOS architecture allows parallel execution of multiple tasks on separate threads, making it ideal for this application. It is easily programmed using XC (a subset of C). The necessary communication interfaces were implemented in software, including Ethernet, with significant cost and time reduction compared to an FPGA-based approach.

A simple approach to control the chopper, calibration mirror, and gimbal for the airborne SMLS was needed. The XMOS board allows for multiple threads and real-time data acquisition. The XC-2 development kit is an attractive choice for synchronized, real-time, event-driven applications. The XMOS is based on the transputer microprocessor architecture developed for parallel computing, which is being revamped in this new platform.

The XMOS device has multiple cores capable of running parallel applications on separate threads. The threads communicate with each other via user-defined channels capable of transmitting data within the device. XMOS provides a C-based development environment using XC, which eliminates the need for custom tool kits associated with FPGA programming. The XC-2 has four cores and necessary hardware for Ethernet I/O.

This work was done by Robert F. Jarnot of Caltech and William J. Bowden of the University of British Columbia 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 Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-48054.

Receiver Gain Modulation Circuit

Applications would be in testing and development of new algorithms to detect gain anomalies and correct drifts that affect climate-quality measurements over an accelerated time scale.

Goddard Space Flight Center, Greenbelt, Maryland

A receiver gain modulation circuit (RGMC) was developed that modulates the power gain of the output of a radiometer receiver with a test signal. As the radiometer receiver switches between calibration noise references, the test signal is mixed with the calibrated noise and thus produces an ensemble set of measurements from which ensemble statistical analysis can be used to extract statistical information about the test signal. The RGMC is an enabling technology of the ensemble detector. As a key component for achieving ensemble detection and analysis, the RGMC

has broad aeronautical and space applications. The RGMC can be used to test and develop new calibration algorithms, for example, to detect gain anomalies, and/or correct for slow drifts that affect climate-quality measurements over an accelerated time scale.

A generalized approach to analyzing radiometer system designs yields a mathematical treatment of noise reference measurements in calibration algorithms. By treating the measurements from the different noise references as ensemble samples of the receiver state, i.e. receiver gain, a quantitative description of the

non-stationary properties of the underlying receiver fluctuations can be derived. Excellent agreement has been obtained between model calculations and radiometric measurements. The mathematical formulation is equivalent to modulating the gain of a stable receiver with an externally generated signal and is the basis for ensemble detection and analysis (EDA).

The concept of generating ensemble data sets using an ensemble detector is similar to the ensemble data sets generated as part of ensemble empirical mode decomposition (EEMD) with exception

of a key distinguishing factor. EEMD adds noise to the signal under study whereas EDA mixes the signal with calibrated noise. It is mixing with calibrated noise that permits the measurement of temporal-functional variability of uncertainty in the underlying process.

The RGMC permits the evaluation of EDA by modulating the receiver gain using an external signal. Without the RGMC, samples of calibrated references from radiometers form an ensemble

data set of the natural occurring fluctuations within a receiver. By driving the gain of an otherwise stable receiver with an external signal, the conceptual framework and generalization of the mathematics of EDA can be tested. A series of measurements was conducted to evaluate and characterize the performance of the RGMC. Test signals stepped the RGMC across its dynamic range of performance using a radiometer that sampled four noise references; analysis

indicates that the RGMC successfully modulated the receiver gain with an external signal. Calibration algorithms applied to four noise references demonstrate the RGMC produced ensemble data sets of the external signal.

This work was done by Hollis Jones and Paul Racette of Goddard Space Flight Center and David Walker and Dazhen Gu of the National Institute of Standards and Technology. Further information is contained in a TSP (see page 1). GSC-16188-1

NEXUS Scalable and Distributed Next-Generation Avionics Bus for Space Missions

NASA's Jet Propulsion Laboratory, Pasadena, California

A paper discusses NEXUS, a common, next-generation avionics interconnect that is transparently compatible with wired, fiber-optic, and RF physical layers; provides a flexible, scalable, packet switched topology; is fault-tolerant with sub-microsecond detection/recovery latency; has scalable bandwidth from 1 Kbps to 10 Gbps; has guaranteed real-time determinism with sub-microsecond latency/jitter; has built-in testability; features low power consumption (< 100 mW per Gbps); is lightweight with about a 5,000-logic-gate

footprint; and is implemented in a small Bus Interface Unit (BIU) with reconfigurable back-end providing interface to legacy subsystems.

NEXUS enhances a commercial interconnect standard, Serial RapidIO, to meet avionics interconnect requirements without breaking the standard. This unified interconnect technology can be used to meet performance, power, size, and reliability requirements of all ranges of equipment, sensors, and actuators at chip-to-chip, board-to-board, or box-to-box boundary.

Early results from in-house modeling activity of Serial RapidIO using VisualSim indicate that the use of a switched, high-performance avionics network will provide a quantum leap in spacecraft onboard science and autonomy capability for science and exploration missions.

This work was done by Yutao He, Eddy Shalom, Savio N. Chau, Raphael R. Some, and Gary S. Bolotin of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47653

Digital Interface Board to Control Phase and Amplitude of Four Channels

A small set of short, high-level commands provides a simple programming interface for an external controller.

NASA's Jet Propulsion Laboratory, Pasadena, California

An increasing number of parts are designed with digital control interfaces, including phase shifters and variable attenuators. When designing an antenna array in which each antenna has independent amplitude and phase control, the number of digital control lines that must be set simultaneously can grow very large. Use of a parallel interface would require separate line drivers, more parts, and thus additional failure points. A convenient form of control where single-phase shifters or attenuators could be set or the whole set could be programmed with an update rate of 100 Hz is needed to solve this problem.

A digital interface board with a field-

programmable gate array (FPGA) can simultaneously control an essentially arbitrary number of digital control lines with a serial command interface requiring only three wires. A small set of short, high-level commands provides a simple programming interface for an external controller. Parity bits are used to validate the control commands. Output timing is controlled within the FPGA to allow for rapid update rates of the phase shifters and attenuators.

This technology has been used to set and monitor eight 5-bit control signals via a serial UART (universal asynchronous receiver/transmitter) interface. The digital interface board controls

the phase and amplitude of the signals for each element in the array. A host computer running Agilent VEE sends commands via serial UART connection to a Xilinx VirtexII FPGA. The commands are decoded, and either outputs are set or telemetry data is sent back to the host computer describing the status and the current phase and amplitude settings.

This technology is an integral part of a closed-loop system in which the angle of arrival of an X-band uplink signal is detected and the appropriate phase shifts are applied to the Ka-band downlink signal to electronically steer the array back in the direction of the

uplink signal. It will also be used in the non-beam-steering case to compensate for phase shift variations through power amplifiers. The digital interface board can be used to set four 5-bit phase shifters and four 5-bit attenuators and monitor their current settings. Additionally, it is useful outside of the closed-loop system for beam-steering alone.

When the VEE program is started, it prompts the user to initialize variables

(to zero) or skip initialization. After that, the program enters into a continuous loop waiting for the telemetry period to elapse or a button to be pushed. A telemetry request is sent when the telemetry period is elapsed (every five seconds). Pushing one of the set or reset buttons will send the appropriate command. When a command is sent, the interface status is returned, and the user will be notified by a pop-up window if any error has occurred. The pro-

gram runs until the End Program button is depressed.

This work was done by Amy E. Smith, Brian M. Cook, Abdur R. Khan, and James P. Lux of Caltech, for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-42778.

CoNeCT Baseband Processor Module

Goddard Space Flight Center, Greenbelt, Maryland

A document describes the CoNeCT Baseband Processor Module (BPM) based on an updated processor, memory technology, and field-programmable gate arrays (FPGAs). The BPM was developed from a requirement to provide sufficient computing power and memory storage to conduct experiments for a Software Defined Radio (SDR) to be implemented.

The flight SDR uses the AT697 SPARC processor with on-chip data and instruction cache. The non-volatile memory has been increased from a 20-Mbit EEPROM (electrically erasable programmable read only memory) to a 4-Gbit Flash, managed by the RTAX2000 Housekeeper, allowing

more programs and FPGA bit-files to be stored. The volatile memory has been increased from a 20-Mbit SRAM (static random access memory) to a 1.25-Gbit SDRAM (synchronous dynamic random access memory), providing additional memory space for more complex operating systems and programs to be executed on the SPARC. All memory is EDAC (error detection and correction) protected, while the SPARC processor implements fault protection via TMR (triple modular redundancy) architecture.

Further capability over prior BPM designs includes the addition of a second FPGA to implement features beyond the

resources of a single FPGA. Both FPGAs are implemented with Xilinx Virtex-II and are interconnected by a 96-bit bus to facilitate data exchange. Dedicated 1.25-Gbit SDRAMs are wired to each Xilinx FPGA to accommodate high rate data buffering for SDR applications as well as independent SpaceWire interfaces. The RTAX2000 manages scrub and configuration of each Xilinx.

This work was done by Clifford K. Yamamoto, Thomas C. Jedrey, and Daniel G. Gutrich of Caltech, and Richard L. Goodpasture of Mantech SRS Technologies for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47773

Cryogenic 160-GHz MMIC Heterodyne Receiver Module

Applications include portable security sensors, hidden weapons detection, airport security, and automotive radar.

NASA's Jet Propulsion Laboratory, Pasadena, California

A cryogenic 160-GHz MMIC heterodyne receiver module has demonstrated a system noise temperature of 100 K or less at 166 GHz. This module builds upon work previously described in "Development of a 150-GHz MMIC Module Prototype for Large-Scale CMB Radiation" (NPO-47664), *NASA Tech Briefs*, Vol. 35, No. 8 (August 2011), p. 27. In the original module, the local oscillator signal was saturating the MMIC low-noise amplifiers (LNAs) with power. In order to suppress the local oscillator signal from reaching the MMIC LNAs, the W-band (75–110 GHz) signal had to be filtered out before reaching 140–170 GHz. A bandpass filter was developed to cover 120–170 GHz, using microstrip parallel-coupled lines to

achieve the desired filter bandwidth, and ensure that the unwanted W-band local oscillator signal would be sufficiently suppressed.

With the new bandpass filter, the entire receiver can work over the 140–180-GHz band, with a minimum system noise temperature of 460 K at 166 GHz. The module was tested cryogenically at 20 K ambient temperature, and it was found that the receiver had a noise temperature of 100 K over an 8-GHz bandwidth.

The receiver module now includes a microstrip bandpass filter, which was designed to have a 3-dB bandwidth of approximately 120–170 GHz. The filter was fabricated on a 3-mil-thick alumina substrate. The filter design was based on a W-band filter design made at JPL

and used in the QUIET (Q/U Imaging Experiment) radiometer modules. The W-band filter was scaled for a new center frequency of 150 GHz, and the microstrip segments were changed accordingly. Also, to decrease the bandwidth of the resulting scaled design, the center gaps between the microstrip lines were increased (by four micrometers in length) compared to the gaps near the edges.

The use of the 150-GHz bandpass filter has enabled the receiver module to function well at room temperature. The system noise temperature was measured to be less than 600 K (at room temperature) from 154 to 168 GHz. Additionally, the use of a W-band isolator between the receiver module and the local oscillator source also

improved the noise temperature substantially. This may be because the mixer was presented with a better impedance match with the use of the isolator.

Cryogenic testing indicates a system noise temperature of 100 K or less at 166 GHz. Prior tests of the MMIC amplifiers alone have resulted in a system noise temperature of 65–70 K in the same frequency range (≈ 160 GHz) when cooled to an ambient temperature of 20 K. While other detector systems may be slightly more sensitive

(such as SIS mixers), they require more cooling (to 4 K ambient) and are not as easily scalable to build a large array, due to the need for large magnets and other equipment.

When cooled to 20 K, this receiver module achieves approximately 100 K system noise temperature, which is slightly higher than single-amplifier module results obtained at JPL (65–70 K when an amplifier is corrected for back-end noise contributions). If this performance can be realized in practice, and a scalable

array can be produced, the impact on cosmic microwave background experiments, astronomical and Earth spectroscopy, interferometry, and radio astronomy in general will be dramatic.

This work was done by Lorene A. Samoska, Mary M. Soria, Heather R. Owen, Douglas E. Dawson, Pekka P. Kangaslahti, and Todd C. Gaier of Caltech, and Patricia Voll, Judy Lau, Matt Sieth, and Sarah Church of Stanford University for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47873

Ka-Band, Multi-Gigabit-Per-Second Transceiver

John H. Glenn Research Center, Cleveland, Ohio

A document discusses a multi-Gigabit-per-second, Ka-band transceiver with a software-defined modem (SDM) capable of digitally encoding/decoding data and compensating for linear and nonlinear distortions in the end-to-end system, including the traveling-wave tube amplifier (TWTA). This innovation can increase data rates of space-to-ground communication links, and has potential application to NASA's future space-based Earth observation system.

The SDM incorporates an extended version of the industry-standard DVB-S2, and LDPC rate 9/10 FEC codec. The SDM supports a suite of waveforms, in-

cluding QPSK, 8-PSK, 16-APSK, 32-APSK, 64-APSK, and 128-QAM. The Ka-band and TWTA deliver an output power on the order of 200 W with efficiency greater than 60%, and a passband of at least 3 GHz. The modem and the TWTA together enable a data rate of 20 Gbps with a low bit error rate (BER).

The payload data rates for spacecraft in NASA's integrated space communications network can be increased by an order of magnitude ($>10\times$) over current state-of-practice. This innovation enhances the data rate by using bandwidth-efficient modulation techniques, which transmit a higher number of bits per

Hertz of bandwidth than the currently used quadrature phase shift keying (QPSK) waveforms.

This work was done by Rainee N. Simons and Edwin G. Wintucky of Glenn Research Center; and Francis J. Smith, Johnny M. Harris, David G. Landon, Osama S. Haddadin, William K. McIntire, and June Y. Sun of L-3 Communications Systems-West. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18735-1.

All-Solid-State 2.45-to-2.78-THz Source

Applications include laboratory spectroscopy, THz imaging, and heterodyne instrumentation.

NASA's Jet Propulsion Laboratory, Pasadena, California

Sources in the THz range are required in order for NASA to implement heterodyne instruments in this frequency range. The source that has been demonstrated here will be used for an instrument on the SOFIA platform as well as for upcoming astrophysics missions. There are currently no electronic sources in the 2–3-THz frequency range. An electronically tunable compact source in this frequency range is needed for lab spectroscopy as well as for compact space-deployable heterodyne receivers. This solution for obtaining useful power levels in the 2–3-THz range is based on utilizing power-combined multiplier stages. Utilizing power combining, the input power can be distributed between different mul-

tiplier chips and then recombined after the frequency multiplication.

A continuous wave (CW) coherent source covering 2.48–2.75 THz, with greater than 10 percent instantaneous and tuning bandwidth, and having 1–14 μW of output power at room temperature, has been demonstrated. This source is based on a 91.8–101.8-GHz synthesizer followed by a power amplifier and three cascaded frequency triplers. It demonstrates that purely electronic solid-state sources can generate a useful amount of power in a region of the electromagnetic spectrum where lasers (solid-state or gas) were previously the only available coherent sources. The bandwidth, agility, and operability of this

THz source has enabled wideband, high-resolution spectroscopic measurements of water, methanol, and carbon monoxide with a resolution and signal-to-noise ratio unmatched by other existing systems, providing new insight in the physics of these molecules. Furthermore, the power and optical beam quality are high enough to observe the Lamb-dip effect in water. The source frequency has an absolute accuracy better than 1 part in 10^{12} , and the spectrometer achieves sub-Doppler frequency resolution better than 1 part in 10^8 . The harmonic purity is better than 25 dB.

This source can serve as a local oscillator for a variety of heterodyne systems, and can be used as a method for preci-

sion control of more powerful but much less frequency-agile quantum mechanical terahertz sources.

This work was done by Imran Mehdi, Goutam Chattopadhyay, Erich T. Schlecht,

Robert H. Lin, Seth Sin, Alejandro Peralta, Choonsup Lee, John J. Gill, John C. Pearson, Paul F. Goldsmith, Peter H. Siegel, Brian J. Drouin, and Peter J. Bruneau of Caltech; Bertrand C. Thomas of ORAU/NPP; Alain

Maestrini of Observatoire de Paris; and John Ward of Raytheon for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47903

Onboard Interferometric SAR Processor for the Ka-band Radar Interferometer (KaRIn)

NASA's Jet Propulsion Laboratory, Pasadena, California

An interferometric synthetic aperture radar (SAR) onboard processor concept and algorithm has been developed for the Ka-band radar interferometer (KaRIn) instrument on the Surface and Ocean Topography (SWOT) mission. This is a mission-critical subsystem that will perform interferometric SAR processing and multi-look averaging over the oceans to decrease the data rate by three orders of magnitude, and therefore enable the downlink of the radar data to the ground.

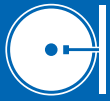
The onboard processor performs demodulation, range compression, co-

registration, and re-sampling, and forms nine azimuth squinted beams. For each of them, an interferogram is generated, including common-band spectral filtering to improve correlation, followed by averaging to the final 1×1-km ground resolution pixel. The onboard processor has been prototyped on a custom FPGA-based cPCI board, which will be part of the radar's digital subsystem.

The level of complexity of this technology, dictated by the implementation of interferometric SAR process-

ing at high resolution, the extremely tight level of accuracy required, and its implementation on FPGAs are unprecedented at the time of this reporting for an onboard processor for flight applications.

This work was done by Daniel Esteban-Fernandez, Ernesto Rodriguez, Eva Peral, Duane I. Clark, and Xiaoqing Wu of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47789



Space Environments Testbed

Goddard Space Flight Center, Greenbelt, Maryland

The Space Environments Testbed (SET) is a flight controller data system for the Common Carrier Assembly. The SET-1 flight software provides the command, telemetry, and experiment control to ground operators for the SET-1 mission.

Modes of operation (see diagram) include:

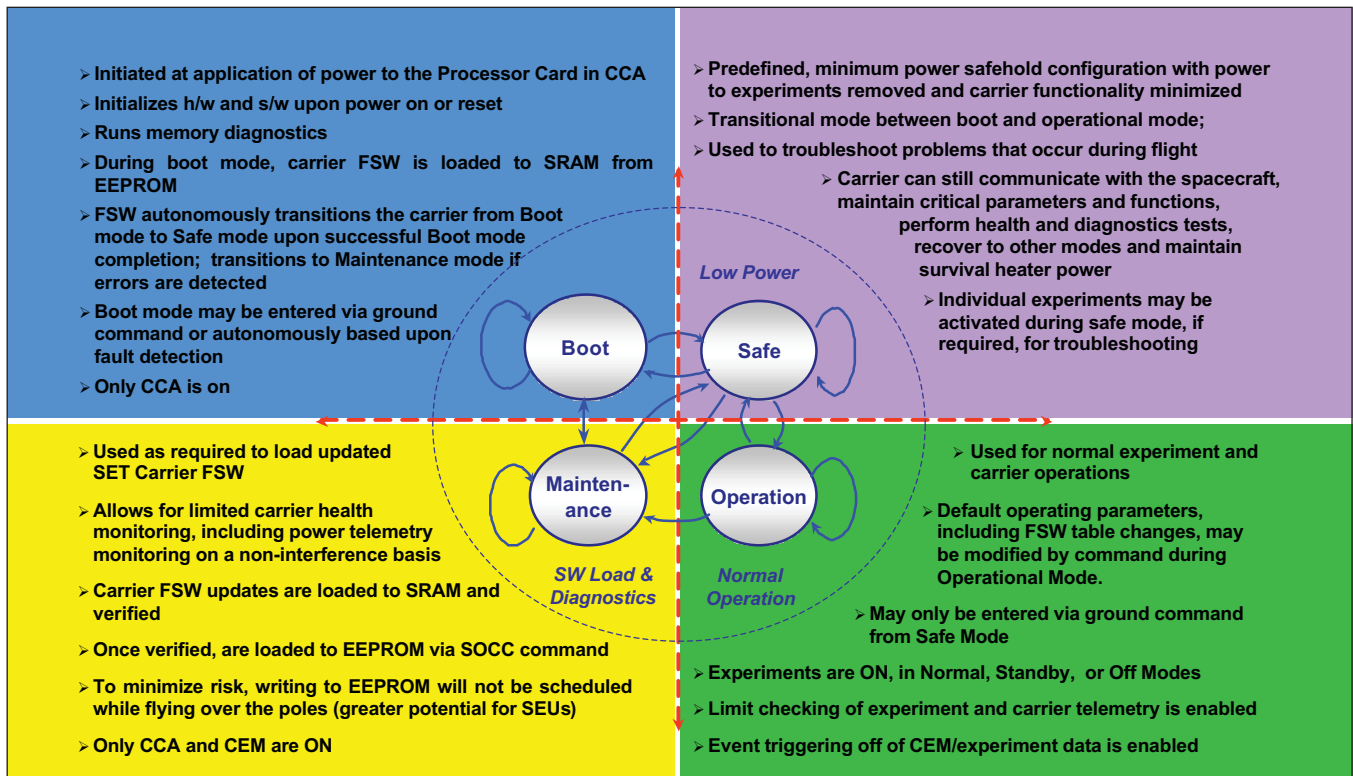
- Boot Mode that is initiated at application of power to the processor card, and runs memory diagnostics. It may be entered via ground command or autonomously based upon fault detection.

• Maintenance Mode that allows for limited carrier health monitoring, including power telemetry monitoring on a non-interference basis.

- Safe Mode is a predefined, minimum power safehold configuration with power to experiments removed and carrier functionality minimized. It is used to troubleshoot problems that occur during flight.

- Operations Mode is used for normal experiment carrier operations. It may be entered only via ground command from Safe Mode.

This work was done by David K. Leucht and Anne Marie J. Koslosky of Goddard Space Flight Center; David L. Kobe and Jya-Chang C. Wu of The Hammers Co.; and David A. Vavra of STG, Inc. Further information is contained in a TSP (see page 1). GSC-15821-1



Mode State Diagram.

High-Performance 3D Articulated Robot Display

NASA's Jet Propulsion Laboratory, Pasadena, California

In the domain of telerobotic operations, the primary challenge facing the operator is to understand the state of the robotic platform. One key aspect of understanding the state is to visualize the physical location and configuration of the platform.

As there is a wide variety of mobile robots, the requirements for visualizing their configurations vary diversely across different platforms. There can also be diversity in the mechanical mobility, such as

wheeled, tracked, or legged mobility over surfaces.

Adaptable 3D articulated robot visualization software can accommodate a wide variety of robotic platforms and environments. The visualization has been used

for surface, aerial, space, and water robotic vehicle visualization during field testing. It has been used to enable operations of wheeled and legged surface vehicles, and can be readily adapted to facilitate other mechanical mobility solutions.

The 3D visualization can render an articulated 3D model of a robotic platform for any environment. Given the model, the software receives real-time telemetry from the avionics system onboard the vehicle and animates the robot visualization to reflect the telemetered physical state. This is used to track the position and attitude in real time to monitor the progress of the vehicle as it traverses its environment. It is also used to monitor the state of any or all articulated elements of the vehicle, such as arms, legs, or control sur-

faces. The visualization can also render other sorts of telemetered states visually, such as stress or strains that are measured by the avionics. Such data can be used to color or annotate the virtual vehicle to indicate nominal or off-nominal states during operation.

The visualization is also able to render the simulated environment where the vehicle is operating. For surface and aerial vehicles, it can render the terrain under the vehicle as the avionics sends it location information (GPS, odometry, or star tracking), and locate the vehicle over or on the terrain correctly. For long traverses over terrain, the visualization can stream in terrain piecewise in order to maintain the current area of interest for the operator without incurring un-

reasonable resource constraints on the computing platform. The visualization software is designed to run on laptops that can operate in field-testing environments without Internet access, which is a frequently encountered situation when testing in remote locations that simulate planetary environments such as Mars and other planetary bodies.

This work was done by Mark W. Powell, Recaredo J. Torres, David S. Mittman, James A. Kurien, and Lucy Abramyan of Caltech 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 Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47945.

Athena

NASA's Jet Propulsion Laboratory, Pasadena, California

The Athena simulation software supports an analyst from DoD or other federal agency in making stability and reconstruction projections for operational analyses in areas like Iraq or Afghanistan. It encompasses the use of all elements of national power: diplomatic, information, military, and economic (DIME), and anticipates their effects on political, military, economic, social, information, and infrastructure (PMESII) variables in real-world battle space environments. Athena is a stand-alone model that provides analysts with insights into the ef-

fectiveness of complex operations by anticipating second-, third-, and higher-order effects. For example, the first-order effect of executing a curfew may be to reduce insurgent activity, but it may also reduce consumer spending and keep workers home as second-order effects. Reduced spending and reduced labor may reduce the gross domestic product (GDP) as a third-order effect. Damage to the economy will have further consequences.

The Athena approach has also been considered for application in studies related to climate change and the smart

grid. It can be applied to any project where the impacts on the population and their perceptions are important, and where population perception is important to the success of the project.

This work was done by Robert G. Chamberlain, William H. Duquette, Joseph P. Provenzano, and Theodore J. Brunzie of Caltech, and Benjamin Jordan of the U.S. Army for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47857.

In Situ Surface Characterization

NASA's Jet Propulsion Laboratory, Pasadena, California

Operation of *in situ* space assets, such as rovers and landers, requires operators to acquire a thorough understanding of the environment surrounding the spacecraft. The following programs help with that understanding by providing higher-level information characterizing the surface, which is not immediately obvious by just looking at the XYZ terrain data.

This software suite covers three primary programs: marsuvw, marsrough, and marsslope, and two secondary programs, which together use XYZ data derived from *in situ* stereo imagery to

characterize the surface by determining surface normal, surface roughness, and various aspects of local slope, respectively.

These programs all use the Planetary Image Geometry (PIG) library to read mission-specific data files. The programs themselves are completely multimission; all mission dependencies are handled by PIG. The input data consists of images containing XYZ locations as derived by, e.g., marsxyz.

The marsuvw program determines surface normals from XYZ data by gathering

XYZ points from an area around each pixel and fitting a plane to those points. Outliers are rejected, and various consistency checks are applied. The result shows the orientation of the local surface at each point as a unit vector. The program can be run in two modes: standard, which is typically used for *in situ* arm work, and slope, which is typically used for rover mobility. The difference is primarily due to optimizations necessary for the larger patch sizes in the slope case.

The marsrough program determines surface roughness in a small area

around each pixel, which is defined as the maximum peak-to-peak deviation from the plane perpendicular to the surface normal at that pixel.

The `marsslope` program takes a surface normal file as input and derives one of several slope-like outputs from it. The outputs include slope, slope rover direction (a measure of slope radially away from the rover), slope heading, slope magnitude, northerly tilt, and solar energy (compares the slope with the Sun's location at local noon).

The `marsuvwproj` program projects a surface normal onto an arbitrary plane

in space, resulting in a normalized 3D vector, which is constrained to lie in the plane. The `marsuvwrot` program rotates the vectors in a surface normal file, generating a new surface normal file. It also can change coordinate systems for an existing surface normal file.

While the algorithms behind this suite are not particularly unique, what makes the programs useful is their integration into the larger *in situ* image processing system via the PIG library. They work directly with space *in situ* data, understanding the appropriate image metadata fields and updating them properly.

The secondary programs (`marsuvwproj`, `marsuvwrot`) were originally developed to deal with anomalous situations on Opportunity and Spirit, respectively, but may have more general applicability.

This work was done by Robert G. Deen, Patrick C. Leger, and Igor Yanovsky of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47724.

Ndarts

NASA's Jet Propulsion Laboratory, Pasadena, California

Ndarts software provides algorithms for computing quantities associated with the dynamics of articulated, rigid-link, multibody systems. It is designed as a general-purpose dynamics library that can be used for the modeling of robotic platforms, space vehicles, molecular dynamics, and other such applications. The architecture and algorithms in Ndarts are based on the Spatial Operator Algebra (SOA) theory for computational multibody and robot dynam-

ics developed at JPL. It uses minimal, internal coordinate models. The algorithms are low-order, recursive scatter/gather algorithms.

In comparison with the earlier Darts++ software, this version has a more general and cleaner design needed to support a larger class of computational dynamics needs. It includes a frames infrastructure, allows algorithms to operate on subgraphs of the system, and implements lazy and deferred computation for better efficiency.

Dynamics modeling modules such as Ndarts are core building blocks of control and simulation software for space, robotic, mechanism, bio-molecular, and material systems modeling.

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

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47703.



Cryo-Etched Black Silicon for Use as Optical Black

NASA's Jet Propulsion Laboratory, Pasadena, California

Stray light reflected from the surface of imaging spectrometer components — in particular, the spectrometer slit — degrade the image quality. A technique has been developed for rapid, uniform, and cost-effective black silicon formation based on inductively coupled plasma (ICP) etching at cryogenic temperatures. Recent measurements show less than 1-percent total reflectance from 350–2,500 nm of doped black silicon formed in this way, making it an excellent option for texturing of component surfaces for reduction of stray light.

Oxygen combines with $\text{SF}_6 + \text{Si}$ etch byproducts to form a passivation layer atop the Si when the etch is performed at cryogenic temperatures. Excess flow of oxygen results in micromasking and the formation of black silicon. The process is repeatable and reliable, and provides control over etch depth and sidewall profile. Density of the needles can be controlled to some extent.

Regions to be textured can be patterned lithographically. Adhesion is not an issue as the nanotips are part of the underlying substrate. This is in contrast to surface growth/deposition tech-

niques such as carbon nanotubes (CNTs).

The black Si surface is compatible with wet processing, including processing with solvents, the textured surface is completely inorganic, and it does not outgas.

In radiometry applications, optical absorbers are often constructed using “gold black” or CNTs. This black silicon technology is an improvement for these types of applications.

This work was done by Karl Y. Yee, Victor E. White, Pantazis Mouroulis, and Michael L. Eastwood of Caltech for NASA's Jet Propulsion Laboratory. NPO-47883

Advanced CO₂ Removal and Reduction System

Lyndon B. Johnson Space Center, Houston, Texas

An advanced system for removing CO₂ and H₂O from cabin air, reducing the CO₂, and returning the resulting O₂ to the air is less massive than is a prior system that includes two assemblies — one for removal and one for reduction. Also, in this system, unlike in the prior system, there is no need to compress and temporarily store CO₂. In this present system, removal and reduction take place within a single assembly, wherein removal is effected by use of an alkali

sorbent and reduction is effected using a supply of H₂ and Ru catalyst, by means of the Sabatier reaction, which is $\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + \text{O}_2$. The assembly contains two fixed-bed reactors operating in alternation: At first, air is blown through the first bed, which absorbs CO₂ and H₂O. Once the first bed is saturated with CO₂ and H₂O, the flow of air is diverted through the second bed and the first bed is regenerated by supplying it with H₂ for the Sabatier reac-

tion. Initially, the H₂ is heated to provide heat for the regeneration reaction, which is endothermic. In the later stages of regeneration, the Sabatier reaction, which is exothermic, supplies the heat for regeneration.

This work was done by Gokhan Alptekin, Margarita Dubovik, and Robert J. Copeland of TDA Research, Inc., for Johnson Space Center. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809. MSC-23480-1/4523-1

Correcting Thermal Deformations in an Active Composite Reflector

Composite actuators can be embedded into an easy-to-manufacture flat surface.

NASA's Jet Propulsion Laboratory, Pasadena, California

Large, high-precision composite reflectors for future space missions are costly to manufacture, and heavy. An active composite reflector capable of adjusting shape *in situ* to maintain required tolerances can be lighter and cheaper to manufacture.

An active composite reflector testbed was developed that uses an array of

piezoelectric composite actuators embedded in the back face sheet of a 0.8-m reflector panel. Each individually addressable actuator can be commanded from –500 to +1,500 V, and the flatness of the panel can be controlled to tolerances of 100 nm. Measuring the surface flatness at this resolution required the use of

a speckle holography interferometer system in the Precision Environmental Test Enclosure (PETE) at JPL.

The existing testbed combines the PETE for test environment stability, the speckle holography system for measuring out-of-plane deformations, the active panel including an array of individ-

ually addressable actuators, a FLIR thermal camera to measure thermal profiles across the reflector, and a heat source. Use of an array of flat piezoelectric actuators to correct thermal deformations is a promising new application for these actuators, as is the use of this actuator technology for surface flatness and wavefront control. An isogrid of these actuators is moving one step closer to a fully active face sheet, with the significant advantage of ease in manufacturing. No extensive rib structure or other actuation backing structure is required, as these actuators can

be applied directly to an easy-to-manufacture flat surface.

Any mission with a surface flatness requirement for a panel or reflector structure could adopt this actuator array concept to create lighter structures and enable improved performance on orbit. The thermal environment on orbit tends to include variations in temperature during shadowing or changes in angle. Because of this, a purely passive system is not an effective way to maintain flatness at the scale of microns over several meters.

This technology is specifically referring to correcting thermal deformations of a

large, flat structure to a specified tolerance. However, the underlying concept (an array of actuators on the back face of a panel for correcting the flatness of the front face) could be extended to many applications, including energy harvesting, changing the wavefront of an optical system, and correcting the flatness of an array of segmented deployable panels.

This work was done by Samuel C. Bradford and Gregory S. Agnes of Caltech, and William K. Wilkie of Langley Research Center for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47755



Umbilical Deployment Device

NASA's next-generation Mars rover encompasses this novel landing technique.

NASA's Jet Propulsion Laboratory, Pasadena, California

The landing scheme for NASA's next-generation Mars rover will encompass a novel landing technique (see figure). The rover will be lowered from a rocket-powered descent stage and then placed onto the surface while hanging from three bridles. Communication between the rover and descent stage will be maintained through an electrical umbilical cable, which will be deployed in parallel with structural bridles.

The 1/2-inch (13-mm) umbilical cable contains a Kevlar rope core, around which wires are wrapped to create a cable. This cable is helically coiled between two concentric truncated cones. It is deployed by pulling one end of the cable from the cone. A retractable mechanism maintains tension on the cable after deployment. A break-tie tethers the umbilical end attached to the rover even after the cable is cut after touchdown. This break-tie allows

the descent stage to develop some velocity away from the rover prior to the cable releasing from the rover deck, then breaks away once the cable is fully extended. The descent stage pulls the cable up so that recontact is not made.

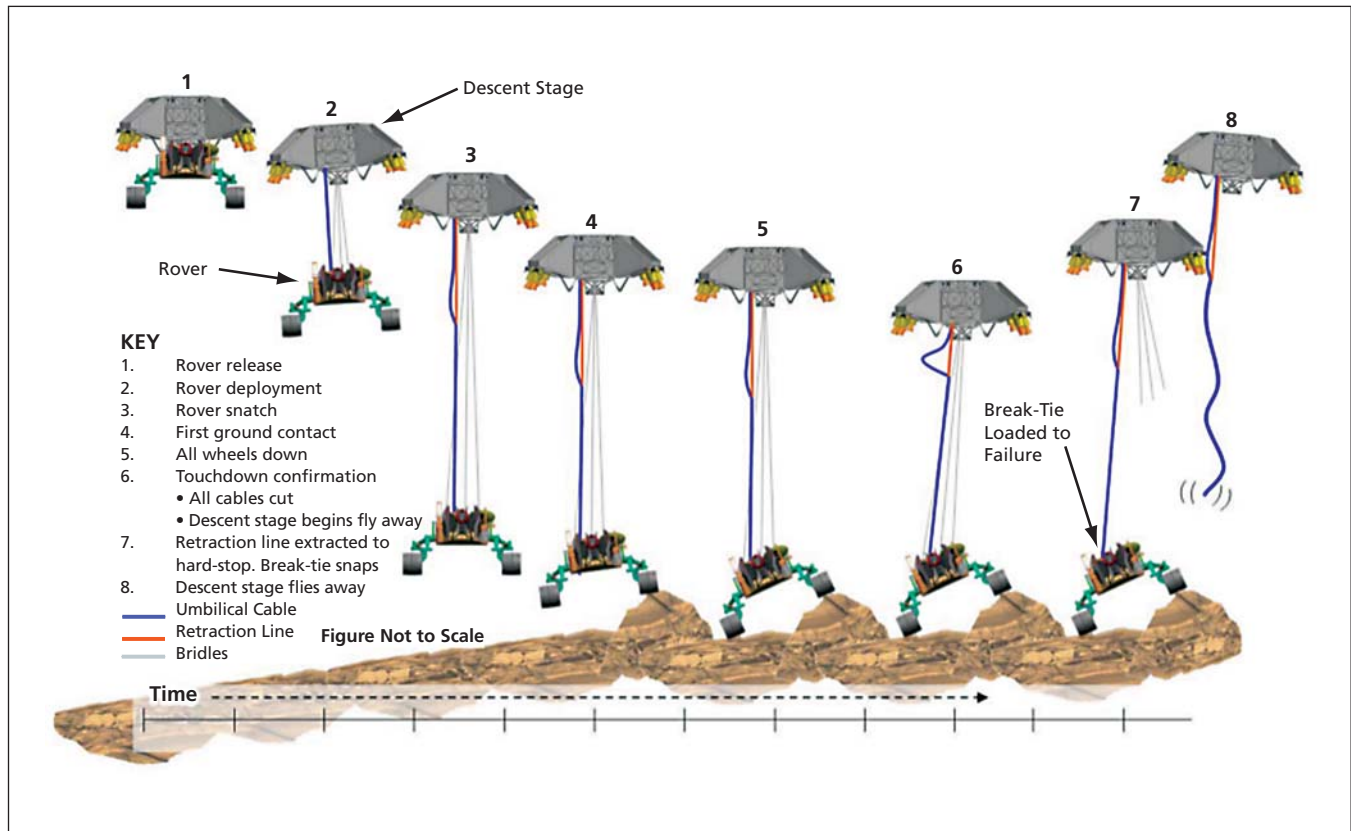
The packaging and deployment technique can store a long length of cable in a relatively small volume while maintaining compliance with the minimum bend radius requirement for the cable being deployed. While the packaging technique could be implemented without the use of break-ties, they were needed in this design due to the vibratory environment and the retraction required by the cable.

The break-ties used created a series of load-spikes in the deployment signature. The load spikes during the deployment of the initial three coils of umbilical showed no increase between the different temperature trials. The cold deploy-

ment did show an increased load requirement for cable extraction in the region where no break-ties were used. This increase in cable drag was superimposed on the loads required to rupture the last set of break-ties, and as such, these loads saw significant increase when compared to their ambient counterparts.

While the loads showed spikes of high magnitude, they were of short duration. Because of this, neither the deployment of the rover, nor the motion of the descent stage, would be adversely affected. In addition, the umbilical was found to have a maximum of 1.2 percent chance for recontact with the ultra-high frequency antenna due to the large margin of safety built in.

This work was done by Michael W. Shafer, John C. Gallon, and Tommaso P. Rivellini of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-46808



Touchdown Sequence for Mars Science Laboratory.

Space Mirror Alignment System

NASA's Jet Propulsion Laboratory, Pasadena, California

An optical alignment mirror mechanism (AMM) has been developed with angular positioning accuracy of ± 0.2 arc-sec. This requires the mirror's linear positioning actuators to have positioning resolutions of ± 112 nm to enable the mirror to meet the angular tip/tilt accuracy requirement. Demonstrated capabilities are ± 0.1 arc-sec angular mirror positioning accuracy, which translates into linear positioning resolutions at the actuator of ± 50 nm.

The mechanism consists of a structure with sets of cross-directional flexures that enable the mirror's tip and tilt motion, a mirror with its kinematic mount, and two linear actuators. An actuator comprises a brushless DC motor, a linear ball screw, and a piezoelectric brake that holds the mirror's position while the unit is unpowered. An interferometric linear position sensor senses the actuator's position. The AMMs were developed for an Astrometric Beam Combiner (ABC) optical

bench, which is part of an interferometer development. Custom electronics were also developed to accommodate the presence of multiple AMMs within the ABC and provide a compact, all-in-one solution to power and control the AMMs.

This work was done by Bruno M. Jau, Colin McKinney, Robert F. Smythe, and Dean L. Palmer of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47928

Thermionic Power Cell To Harness Heat Energies for Geothermal Applications

Possible uses include geothermal exploration, automotive, and renewable energy applications.

NASA's Jet Propulsion Laboratory, Pasadena, California

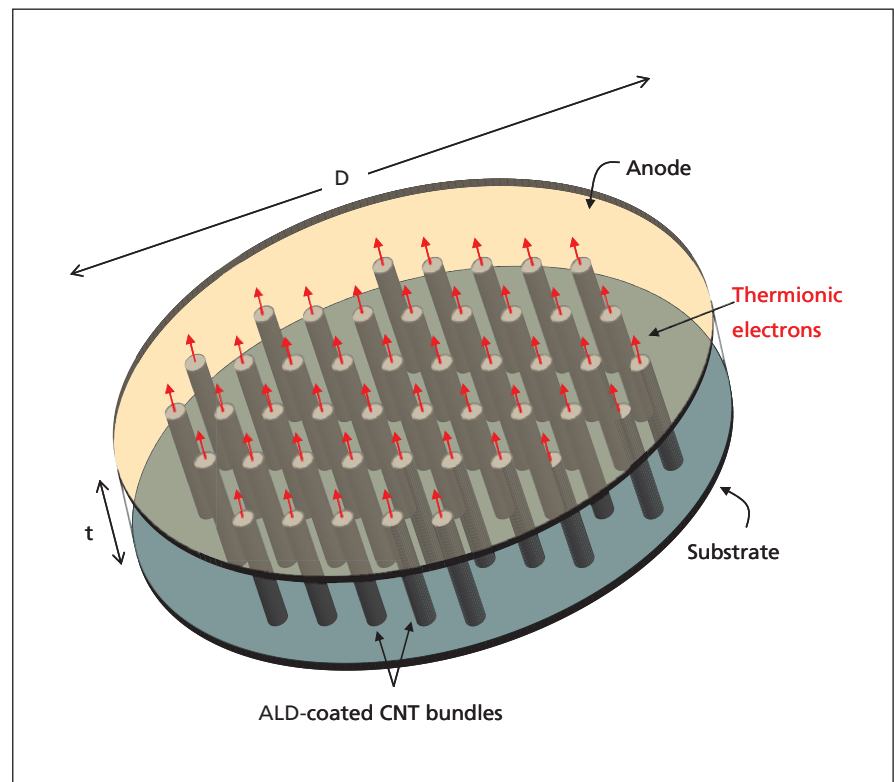
A unit thermionic power cell (TPC) concept has been developed that converts natural heat found in high-temperature environments (460 to 700 °C) into electrical power for *in situ* instruments and electronics. Thermionic emission of electrons occurs when an emitter filament is heated to "white hot" temperatures ($>1,000$ °C) allowing electrons to overcome the potential barrier and emit into the vacuum. These electrons are then collected by an anode, and transported to the external circuit for energy storage.

The thermionic emission current density (A/m^2) = $AT^2e^{(-\phi/kT)}$; where A = a constant, T = temperature (K), ϕ = work function (eV), and k = Boltzmann constant. The efficiency of emission increases with decreasing work function of the emitter material and increasing temperature. For example, the emission efficiency is much higher for cesium ($\phi = 2.4$ eV) compared to pure carbon nanotube (CNT) (4.9 eV) and tungsten (4.5 eV). Additionally, the total current produced can be increased by enhancing the emitter surface area.

In this proposed approach, the higher emission efficiency of low-work function metal is combined with the enormous surface area achievable using CNT bundles to produce mA to A range current at lower temperatures of 460 to 700 °C range. This is achievable by conformally coating CNT (see figure) bundle arrays (or simply arrays of CNTs) with alkali metals such as potassium ($\phi = 2.3$ eV) or

cesium using an atomic layer deposition process. Projected emission area of such an alkali metal-coated CNT bundle array (2- μ m diameter, spaced 2 μ m apart) over a 4-in. (≈ 10 -cm) diameter wafer is $\approx 3.0 \times 10^4$ cm². This leads to an estimated current production of ≈ 500 μ A (> 200

Wh/kg) at 460 °C to ≈ 1.3 A at 700 °C, which is comparable to standard high-temperature batteries (for example, for Na-NiCl₂ high-temperature batteries produce ≈ 90 –130 Wh/kg), and sufficient to power communication, computational and control electronics, as well as sensors



Schematic representation of the Thermionic Power Cell (TPC) with alkali-metal coated CNT bundles to enhance thermionic emission.

and miniature motors. Large areas of TPC or multiple TPC plates can be employed to produce much higher electrical energy to power heavier systems.

This highly miniaturized, high-temperature, long-life power source can be supplementary to primary high-temperature battery. The concept applies famil-

iar thermionic emission principle for power generation by harnessing the local heat in the application environments. The approach of power production and design flexibility naturally provides an attractive option to harness *in situ* heat to produce power enough to operate electronics and miniature instrumentation.

TPC can be designed to support geothermal explorations by harnessing heat energy of the local environment.

This work was done by Harish Manohara, Mohammad Mojaradi, and Harold F. Greer of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-46967

⚙️ Graph Theory Roots of Spatial Operators for Kinematics and Dynamics

These concepts can be applied to modeling, simulation, and control of robots and other mechanisms.

NASA's Jet Propulsion Laboratory, Pasadena, California

Spatial operators have been used to analyze the dynamics of robotic multi-body systems and to develop novel computational dynamics algorithms. Mass matrix factorization, inversion, diagonalization, and linearization are among several new insights obtained using such operators. While initially developed for serial rigid body manipulators, the spatial operators — and the related mathematical analysis — have been shown to extend very broadly including to tree and closed topology systems, to systems with flexible joints, links, etc. This work uses concepts from graph theory to explore the mathematical foundations of spatial operators. The goal is to study and characterize the properties of the spatial operators at an abstract level so that they can be applied to a broader range of dynamics problems.

The rich mathematical properties of the kinematics and dynamics of robotic multibody systems has been an area of strong research interest for several decades. These properties are important

to understand the inherent physical behavior of systems, for stability and control analysis, for the development of computational algorithms, and for model development of faithful models.

Recurring patterns in spatial operators leads one to ask the more abstract question about the properties and characteristics of spatial operators that make them so broadly applicable. The idea is to step back from the specific application systems, and understand more deeply the generic requirements and properties of spatial operators, so that the insights and techniques are readily available across different kinematics and dynamics problems.

In this work, techniques from graph theory were used to explore the abstract basis for the spatial operators. The close relationship between the mathematical properties of adjacency matrices for graphs and those of spatial operators and their kernels were established. The connections hold across very basic requirements on the system topology, the

nature of the component bodies, the indexing schemes, etc. The relationship of the underlying structure is intimately connected with efficient, recursive computational algorithms. The results provide the foundational groundwork for a much broader look at the key problems in kinematics and dynamics.

The properties of general graphs and trees of nodes and edge were examined, as well as the properties of adjacency matrices that are used to describe graph connectivity. The nilpotency property of such matrices for directed trees was reviewed, and the adjacency matrices were generalized to the notion of block weighted adjacency matrices that support block matrix elements. This leads us to the development of the notion of Spatial Kernel Operator SKO kernels. These kernels provide the basis for the development of SKO resolvent operators.

This work was done by Abhinandan Jain of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47313

⚙️ Spacesuit Soft Upper Torso Sizing Systems

This system has application in medical devices for immobilizing injured limbs or applying controlled pressure to areas of the body of a burn victim.

Lyndon B. Johnson Space Center, Houston, Texas

The passive sizing system consists of a series of low-profile pulleys attached to the front and back of the shoulder bearings on a spacesuit soft upper torso (SUT), textile cord or stainless steel cable, and a modified commercial ratchet mechanism. The cord/cable is routed through the pulleys and attached to the ratchet mechanism mounted on

the front of the spacesuit within reach of the suited subject. Upon actuating the ratchet mechanism, the shoulder bearing breadth is changed, providing variable upper torso sizing.

The active system consists of a series of pressurizable nastic cells embedded into the fabric layers of a spacesuit SUT. These cells are integrated to the front and back

of the SUT and are connected to an air source with a variable regulator. When inflated, the nastic cells provide a change in the overall shoulder bearing breadth of the spacesuit and thus, torso sizing.

The research focused on the development of a high-performance sizing and actuation system. This technology has application as a suit-sizing mechanism to

allow easier suit entry and more accurate suit fit with fewer torso sizes than the existing EMU (Extravehicular Mobility Unit) suit system. This advanced SUT will support NASA's Advanced EMU Evolutionary Concept of a two-sizes-fit-all upper torso for replacement of the current EMU hard upper torso (HUT).

Both the passive and nastic sizing system approaches provide astronauts with real-time upper torso sizing, which translates into a more comfortable suit, providing enhanced fit resulting in improved crewmember performance

during extravehicular activity. These systems will also benefit NASA by reducing flight logistics as well as overall suit system cost. The nastic sizing system approach provides additional structural redundancy over existing SUT designs by embedding additional coated fabric and uncoated fabric layers.

Two sizing systems were selected to build into a prototype SUT: one active and one passive. From manned testing, it was found that both systems offer good solutions to sizing a SUT to fit a crewmember. This new system pro-

vided improved suit don/doff over existing spacesuit designs as well as providing better fit at suit operational pressure resulting in improved comfort and mobility.

It was found that a SUT with a sizing system may solve several problems that have plagued existing HUT designs, and that a SUT with a sizing system may be a viable option for advanced suit architectures.

This work was done by David Graziosi and Keith Splawn of ILC Dover, Inc. for Johnson Space Center. Further information is contained in a TSP (see page 1), MSC-24928-1



Radiation Protection Using Single-Wall Carbon Nanotube Derivatives

Stress mitigation protects DNA and other healthy cell components from the effects of radiation therapy or radiation-containing weapons.

Lyndon B. Johnson Space Center, Houston, Texas

This invention is a means of radiation protection, or cellular oxidative stress mitigation, via a sequence of quenching radical species using nano-engineered scaffolds, specifically single-wall carbon nanotubes (SWNTs) and their derivatives. The material can be used as a means of radiation protection by reducing the number of free radicals within, or nearby, organelles, cells, tissue, organs, or living organisms, thereby reducing the risk of damage to DNA and other cellular components (i.e., RNA, mitochondria, membranes, etc.) that can lead to chronic and/or acute pathologies, including but not limited to cancer, cardiovascular disease, immuno-suppression, and disorders of the central nervous system. In addition, this innovation could be used as a prophylactic or antidote for accidental radiation exposure, during high-altitude or space travel where exposure to radiation is anticipated, or to protect from exposure from deliberate terrorist or wartime use of radiation-containing weapons.

BHA and BHT are well-known food preservatives that are excellent radical scavengers. These compounds, among others, attached to SWNTs make excellent radical traps. The 4-(2-aminoethyl)-

2,6-bis(1,1-dimethylethyl)phenol (amino-BHT, compound 3, Scheme 1) groups are associated with nano-engineering materials. The amino-BHT groups can be associated with SWNTs that have carboxylic acid groups via acid-base association, or via covalent attachment. The SWNTs can also have poly(ethylene glycol) (PEG) chains associated with them to enhance the solubility of the nano-engineered materials in water and buffered systems. Likewise, 4-(2-carboxyethyl)-2,6-bis(1,1-dimethylethyl)phenol (carboxy-BHT, compound 4, Scheme 2) can be associated with aminated SWNTs (i.e., SWNTs that are carboxylated, then aminated via interaction with poly(ethylene imine), again via acid base association.

One idea is to attach 2,6-di(*tert*-butyl)phenols (BHT and BHA analogs) to SWNTs, and to use these as delivery agents to quench large amounts of radicals that can be established in a cell due to oxidative stress or radiation-induced pathways. The *tert*-butyl groups are most properly named as 1,1-dimethylethyl moieties. Many other radical scavengers can be appended to the sidewalls of water-soluble SWNTs via acid-base, covalent or non-covalent (π - π interactions

of Van der Waals interactions) functionalized protocols. In some cases, the parent pluronic-wrapped SWNT can show efficacy in this reaction as well. Two other known therapeutic radical scavengers include Lavendustin B and Amifostin. One skilled in the art can think of several permutations for derivatizing radical scavengers to SWNTs or double-wall nanotubes (DWNTs) for multi-wall nanotubes (MWNTs) where there are three or more walls predominating in a sample.

This work was done by James M. Tour, Meng Lu, Rebecca Lucente-Schultz, Ashley Leonard, Condell Dewayne Doyle, Dimitry V. Kosynkin, and Brandi Katherine Price of Rice University for Johnson Space Center.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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E-mail: techtran@rice.edu*

Refer to MSC-24383-1, volume and number of this NASA Tech Briefs issue, and the page number.

PMA-PhyloChip DNA Microarray To Elucidate Viable Microbial Community Structure

This technology has applications in pharmaceutical and medical equipment manufacturing, and food processing.

NASA's Jet Propulsion Laboratory, Pasadena, California

Since the Viking missions in the mid-1970s, traditional culture-based methods have been used for microbial enumeration by various NASA programs. Viable microbes are of particular concern for spacecraft cleanliness, for forward contamination of extrater-

restrial bodies (proliferation of microbes), and for crew health/safety (viable pathogenic microbes). However, a "true" estimation of viable microbial population and differentiation from their dead cells using the most sensitive molecular methods is a chal-

lenge, because of the stability of DNA from dead cells.

The goal of this research is to evaluate a rapid and sensitive microbial detection concept that will selectively estimate viable microbes. Nucleic acid amplification approaches such as the

polymerase chain reaction (PCR) have shown promise for reducing time to detection for a wide range of applications. The proposed method is based on the use of a fluorescent DNA intercalating agent, propidium monoazide (PMA), which can only penetrate the membrane of dead cells. The PMA-quenched reaction mixtures can be screened, where only the DNA from live cells will be available for subsequent PCR reaction and microarray detection, and be identified as part of the viable microbial community. An additional advantage of the proposed rapid method is that it will detect viable microbes and differentiate from dead cells in only a few hours, as opposed to less comprehensive culture-based assays, which take days to complete. This novel combination approach is called the PMA-Microarray method.

DNA intercalating agents such as PMA have previously been used to selectively distinguish between viable and dead bacterial cells. Once in the cell, the dye intercalates with the DNA and, upon photolysis under visible light,

produces stable DNA adducts. DNA cross-linked in this way is unavailable for PCR. Environmental samples suspected of containing a mixture of live and dead microbial cells/spores will be treated with PMA, and then incubated in the dark. Thereafter, the sample is exposed to visible light for five minutes, so that the DNA from dead cells will be cross-linked. Following this PMA treatment step, the sample is concentrated by centrifugation and washed (to remove excessive PMA) before DNA is extracted. The 16S rRNA gene fragments will be amplified by PCR to screen the total microbial community using PhyloChip DNA microarray analysis. This approach will detect only the viable microbial community since the PMA intercalated DNA from dead cells would be unavailable for PCR amplification. The total detection time including PCR reaction for low biomass samples will be a few hours.

Numerous markets may use this technology. The food industry uses spore detection to validate new alternative food pro-

cessing technologies, sterility, and quality. Pharmaceutical and medical equipment companies also detect spores as a marker for sterility. This system can be used for validating sterilization processes, water treatment systems, and in various public health and homeland security applications.

This work was done by Kasthuri J. Venkateswaran and Christina N. Stam of Caltech, and Gary L. Andersen and Todd DeSantis of Lawrence Berkeley National Laboratory for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-47112, volume and number of this NASA Tech Briefs issue, and the page number.



Lidar Luminance Quantizer

Commercial applications include 3D terrain mapping, urban reconnaissance, facial recognition, and robotic vision.

Goddard Space Flight Center, Greenbelt, Maryland

This innovation addresses challenges in lidar imaging, particularly with the detection scheme and the shapes of the detected signals. Ideally, the echoed pulse widths should be extremely narrow to resolve fine detail at high event rates. However, narrow pulses require wideband detection circuitry with increased power dissipation to minimize thermal noise. Filtering is also required to shape each received signal into a form suitable for processing by a constant fraction discriminator (CFD) followed by a time-to-digital converter (TDC). As the intervals between the echoes decrease, the finite bandwidth of the shaping circuits blends the pulses into an analog signal (luminance) with multiple modes, reducing the ability of the CFD to discriminate individual events.

The lidar luminance quantizer (exemplified in Figure 1) resolves the amplitude, amplitude slope, and temporal characteristics of a luminance echo at the instants the signal crosses a plurality of thresholds. The system is comprised of an n-bit flash quantizer with 2^n-1 high-speed, non-latched comparators, and a k-bit time-to-digital converter (TDC) with 2^k quanta. Each comparator's output is encoded into amplitude (S_{A+} , S_{A-}) and temporal (S_T) data, the latter relative to the illuminating laser flash instant. S_{A+} and S_{A-} are the encoded amplitudes of positive and negative slewing points respectively. When a comparator detects that a threshold has been crossed, it latches the outputs of the amplitude encoder and the TDC as binary words S_{A+} or S_{A-} , and S_T . The interval S_T is the round-trip time from laser emission to detection by a particular comparator. In Figure 1, the S_A and T registers are cascades of parallel k-bit temporal data, n-bit amplitude data, and 1-bit slope sign data, clocked by the associated comparator output so that the data is streamed asynchronously between laser flash instants. The ensemble of measurements allows decomposition of a scene's luminance versus time so that the modes can be resolved resulting in greater image detail. This scheme differs from photon-counting lidar detection systems in that the echoes are quantized in both amplitude and time. An exemplary timing diagram for a complex wave-shape is shown in Figure 2 for a 3-bit amplitude quantization.

The invention is unique in that it combines a slew sensitive flash digitizer function with a temporal encoder to digitize the echoes in the amplitude, derivative, and time domains. Its operation is synchronous with respect to the laser flash instants, but the measured amplitude and temporal points output from the encoder occur asynchronously between flashes. Each threshold crossed is paired with a TDC output value for a plurality of outputs per clock period, unlike a traditional flash digitizer where only one word is output per clock period. This function can be viewed as an equivalent ultra high-speed digitizer in that the amplitude measurements within a clock period can be resolved temporally by the TDC at a very fine level.

This work was done by Gerard Quilligan, Jeffrey DuMonthier, and George Suarez of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15815-1

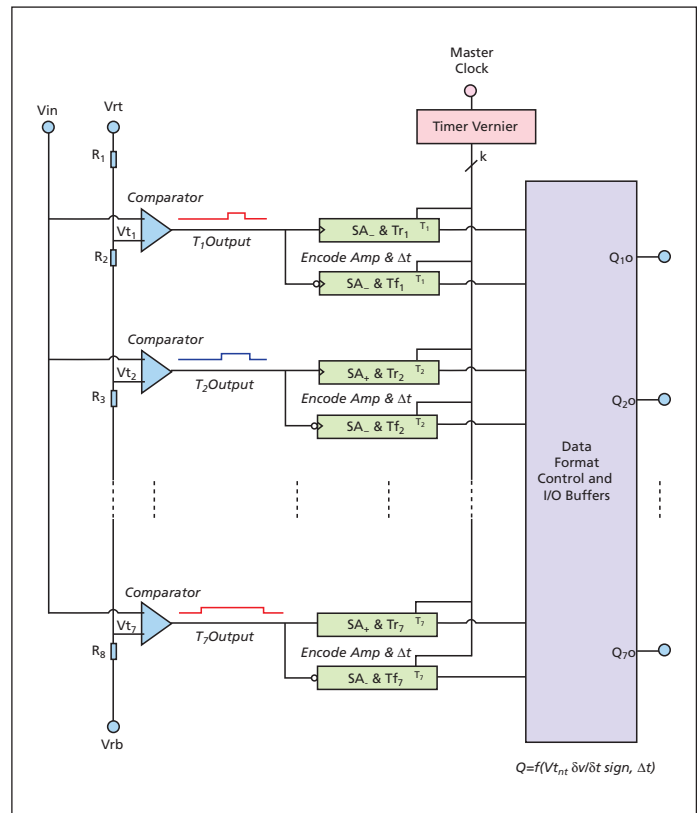


Figure 1. Exemplary 3-bit amplitude/k-bit temporal Lidar Luminance Quantizer block schematic.

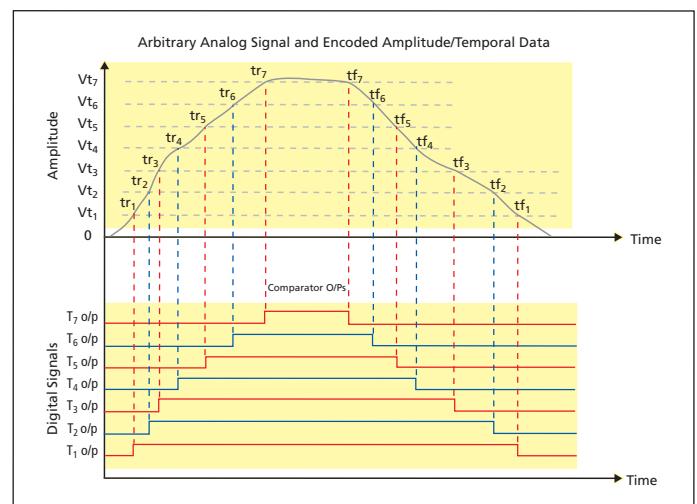


Figure 2. Exemplary 3-bit amplitude/k-bit Temporal Quantization of an arbitrary analog signal.

Distributed Capacitive Sensor for Sample Mass Measurement

NASA's Jet Propulsion Laboratory, Pasadena, California

Previous robotic sample return missions lacked *in situ* sample verification/quantity measurement instruments. Therefore, the outcome of the mission remained unclear until spacecraft return. *In situ* sample verification systems such as this Distributed Capacitive (DisC) sensor would enable an unmanned spacecraft system to re-attempt the sample acquisition procedures until the capture of desired sample quantity is positively confirmed, thereby maximizing the prospect for scientific reward.

The DisC device contains a 10-cm-diameter pressure-sensitive elastic membrane placed at the bottom of a sample canister. The membrane deforms under the weight of accumulating planetary sample. The membrane is positioned in close proximity to an opposing rigid substrate with a narrow gap. The deformation of the membrane

makes the gap narrower, resulting in increased capacitance between the two parallel plates (elastic membrane and rigid substrate). C-V conversion circuits on a nearby PCB (printed circuit board) provide capacitance readout via LVDS (low-voltage differential signaling) interface. The capacitance method was chosen over other potential approaches such as the piezoelectric method because of its inherent temperature stability advantage. A reference capacitor and temperature sensor are embedded in the system to compensate for temperature effects.

The pressure-sensitive membranes are aluminum 6061, stainless steel (SUS) 403, and metal-coated polyimide plates. The thicknesses of these membranes range from 250 to 500 μm . The rigid substrate is made with a 1- to 2-mm-thick wafer of one of the following materials

depending on the application requirements — glass, silicon, polyimide, PCB substrate. The glass substrate is fabricated by a microelectromechanical systems (MEMS) fabrication approach. Several concentric electrode patterns are printed on the substrate. The initial gap between the two plates, 100 μm , is defined by a silicon spacer ring that is anodically bonded to the glass substrate. The fabricated proof-of-concept devices have successfully demonstrated tens to hundreds of picofarads of capacitance change when a simulated sample (100 g to 500 g) is placed on the membrane.

This work was done by Risaku Toda, Colin McKinney, Shannon P. Jackson, Mohammad Mojarradi, Harish Manohara, and Ashitey Trebi-Ollennu of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47690



▶ Base Flow Model Validation

Marshall Space Flight Center, Alabama

A method was developed of obtaining propulsive base flow data in both hot and cold jet environments, at Mach numbers and altitude of relevance to NASA launcher designs. The base flow data was used to perform computational fluid dynamics (CFD) turbulence model assessments of base flow predictive capabilities in order to provide increased confidence in base thermal and pressure load predictions obtained from compu-

tational modeling efforts. Predictive CFD analyses were used in the design of the experiments, available propulsive models were used to reduce program costs and increase success, and a wind tunnel facility was used.

The data obtained allowed assessment of CFD/turbulence models in a complex flow environment, working within a building-block procedure to validation, where cold, non-reacting test data was

first used for validation, followed by more complex reacting base flow validation.

This work was done by Neeraj Sinha and Kevin Brinckman of Combustion Research and Flow Technology, and Bernard Jansen and John Seiner of the University of Mississippi for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32779-1.

▶ Minimum Landing Error Powered-Descent Guidance for Planetary Missions

NASA's Jet Propulsion Laboratory, Pasadena, California

An algorithm improves the accuracy with which a lander can be delivered to the surface of Mars. The main idea behind this innovation is the use of a "lossless convexification," which converts an otherwise non-convex constraint related to thruster throttling to a convex constraint, enabling convex optimization to be used. The convexification leads directly to an algorithm that guarantees finding the global optimum of the original nonconvex optimization problem with a deterministic upper bound on the number of iterations required for convergence.

In this innovation, previous work in powered-descent guidance using convex

optimization is extended to handle the case where the lander must get as close as possible to the target given the available fuel, but is not required to arrive exactly at the target. The new algorithm calculates the minimum-fuel trajectory to the target, if one exists, and calculates the trajectory that minimizes the distance to the target if no solution to the target exists. This approach poses the problem as two Second-Order Cone Programs, which can be solved to global optimality with deterministic bounds on the number of iterations required.

This work was done by Lars Blackmore and Behcet Acikmese of Caltech for NASA's Jet

Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-46647, volume and number of this NASA Tech Briefs issue, and the page number.

▶ Framework for Integrating Science Data Processing Algorithms Into Process Control Systems

This technique can be used for data processing and management systems.

NASA's Jet Propulsion Laboratory, Pasadena, California

A software framework called PCS Task Wrapper is responsible for standardizing the setup, process initiation, execution, and file management tasks surrounding the execution of science data algorithms, which are referred to by NASA as Product Generation Executives (PGEs). PGEs codify a scientific algo-

rithm, some step in the overall scientific process involved in a mission science workflow.

The PCS Task Wrapper provides a stable operating environment to the underlying PGE during its execution lifecycle. If the PGE requires a file, or metadata regarding the file, the PCS

Task Wrapper is responsible for delivering that information to the PGE in a manner that meets its requirements. If the PGE requires knowledge of upstream or downstream PGEs in a sequence of executions, that information is also made available. Finally, if information regarding disk space, or node

information such as CPU availability, etc., is required, the PCS Task Wrapper provides this information to the underlying PGE.

After this information is collected, the PGE is executed, and its output Product file and Metadata generation is managed via the PCS Task Wrapper framework. The innovation is responsible for marshalling output Products and Metadata back to a PCS File Management component for use in downstream data processing and pedigree. In support of

this, the PCS Task Wrapper leverages the PCS Crawler Framework to ingest (during pipeline processing) the output Product files and Metadata produced by the PGE.

The architectural components of the PCS Task Wrapper framework include PGE Task Instance, PGE Config File Builder, Config File Property Adder, Science PGE Config File Writer, and PCS Met file Writer. This innovative framework is really the unifying bridge between the execution of a step in the over-

all processing pipeline, and the available PCS component services as well as the information that they collectively manage.

This work was done by Chris A. Mattmann, Daniel J. Crichton, Albert Y. Chang, Brian M. Foster, Dana J. Freeborn, David M. Woollard, and Paul M. Ramirez of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47160.

▶ Time Synchronization and Distribution Mechanisms for Space Networks

NASA's Jet Propulsion Laboratory, Pasadena, California

This work discusses research on the problems of synchronizing and distributing time information between spacecraft based on the Network Time Protocol (NTP), where NTP is a standard time synchronization protocol widely used in the terrestrial network. The Proximity-1 Space Link Interleaved Time Synchronization (PITS) Protocol was designed and developed for synchronizing spacecraft that are in "proximity" where "proximity" is less than 100,000 km distant. A particular application is synchronization between a Mars orbiter and rover. Lunar scenarios as well as outer-planet deep space mother-ship-probe missions may also apply.

Spacecraft with more accurate time information functions as a time-server,

and the other spacecraft functions as a time-client. PITS can be easily integrated and adaptable to the CCSDS Proximity-1 Space Link Protocol with minor modifications. In particular, PITS can take advantage of the time-stamping strategy that underlying link layer functionality provides for accurate time offset calculation. The PITS algorithm achieves time synchronization with eight consecutive space network time packet exchanges between two spacecraft. PITS can detect and avoid possible errors from receiving duplicate and out-of-order packets by comparing with the current state variables and timestamps. Further, PITS is able to detect error events and autonomously recover from unexpected events that can possibly occur during the time synchro-

nization and distribution process. This capability achieves an additional level of protocol protection on top of CRC or Error Correction Codes. PITS is a lightweight and efficient protocol, eliminating the needs for explicit frame sequence number and long buffer storage.

The PITS protocol is capable of providing time synchronization and distribution services for a more general domain where multiple entities need to achieve time synchronization using a single point-to-point link.

This work was done by Simon S. Woo, Jay L. Gao, and Loren P. Clare of Caltech, and David L. Mills of University of Delaware for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47403

▶ Local Estimators for Spacecraft Formation Flying

NASA's Jet Propulsion Laboratory, Pasadena, California

A formation estimation architecture for formation flying builds upon the local information exchange among multiple local estimators. 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 needed that are scala-

ble, modular, and robust to variations in the topology and link characteristics of the formation exchange network. These distributed algorithms should rely on a local information-exchange network, relaxing the assumptions on existing algorithms.

In this research, it was shown that only local observability is required to design a formation estimator and control law. The approach relies on breaking up the overall information-exchange network into sequence of

local subnetworks, and invoking an agreement-type filter to reach consensus among local estimators within each local network. State estimates were obtained by a set of local measurements that were passed through a set of communicating Kalman filters to reach an overall state estimation for the formation.

An optimization approach was also presented by means of which diffused estimates over the network can be incorporated in the local estimates obtained

by each estimator via local measurements. This approach compares favorably with that obtained by a centralized Kalman filter, which requires complete

knowledge of the raw measurement available to each estimator.

This work was done by Nanaz Fathpour and Fred Y. Hadaegh of Caltech and Mehran

Mesbahi and Marzieh Nabi of the University of Washington for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-46902



Books & Reports

Software-Defined Radio for Space-to-Space Communications

A paper describes the Space-to-Space Communications System (SSCS) Software-Defined Radio (SDR) research project to determine the most appropriate method for creating flexible and reconfigurable radios to implement wireless communications channels for space vehicles so that fewer radios are required, and commonality in hardware and software architecture can be leveraged for future missions. The ability to reconfigure the SDR through software enables one radio platform to be reconfigured to interoperate with many different waveforms. This means a reduction in the number of physical radio platforms necessary to support a space mission's communication requirements, thus decreasing the total size, weight, and power needed for a mission.

This work was done by Ken Fisher and Cindy Jih of Johnson Space Center, and Michael S. Moore, Jeremy C. Price, Ben A. Abbott, and Justin A. Fritz of Southwest Research Institute. Further information is contained in a TSP (see page 1). MSC-24465-1

Reflective Occultation Mask for Evaluation of Occulter Designs for Planet Finding

Advanced formation flying occulter designs utilize a large occulter mask flying in formation with an imaging telescope to block and null starlight to

allow imaging of faint planets in exosolar systems. A paper describes the utilization of subscale reflective occultation masks to evaluate formation flying occulter designs. The use of a reflective mask allows mounting of the occulter by conventional means and simplifies the test configuration.

The innovation alters the test set-up to allow mounting of the mask using standard techniques to eliminate the problems associated with a standard configuration. The modified configuration uses a reflective set-up whereby the star simulator reflects off of a reflective occulting mask and into an evaluation telescope. Since the mask is sized to capture all rays required for the imaging test, it can be mounted directly to a supporting fixture without interfering with the beam.

Functionally, the reflective occultation mask reflects light from the star simulator instead of transmitting it, with a highly absorptive carbon nanotube layer simulating the occulter blocking mask. A subscale telescope images the star source and companion dim source that represents a planet. The primary advantage of this is that the occulter can be mounted conventionally instead of using diffractive wires or magnetic levitation.

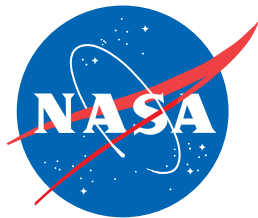
This work was done by John Hagopian, Richard Lyon, Shahram Shiri, and Patrick Roman of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15943-1

Molecular Adsorber Coating

A document discusses a zeolite-based sprayable molecular adsorber coating that has been developed to alleviate the size and weight issues of current ceramic puck-based technology, while providing a configuration that more projects can use to protect against degradation from outgassed materials within a spacecraft, particularly contamination-sensitive instruments. This coating system demonstrates five times the adsorption capacity of previously developed adsorber coating slurries. The molecular adsorber formulation was developed and refined, and a procedure for spray application was developed. Samples were spray-coated and tested for capacity, thermal optical/radiative properties, coating adhesion, and thermal cycling.

Work performed during this study indicates that the molecular adsorber formulation can be applied to aluminum, stainless steel, or other metal substrates that can accept silicate-based coatings. The coating can also function as a thermal-control coating. This adsorber will dramatically reduce the mass and volume restrictions, and is less expensive than the currently used molecular adsorber puck design.

This work was done by Sharon Straka, Wanda Peters, Mark Hasegawa, Randy Hedgeland, and John Petro of Goddard Space Flight Center and Kevin Novo-Gradac, Alfred Wong, Jack Triolo, and Cory Miller of SGT, Inc. Further information is contained in a TSP (see page 1). GSC-16105-1



National Aeronautics and
Space Administration