Information Technology

Numerical Simulation of Rocket Exhaust Interaction With Lunar Soil

These simulations will help predict suitable landing sites on the Moon.

John F. Kennedy Space Center, Florida

This technology development originated from the need to assess the debris threat resulting from soil material erosion induced by landing spacecraft rocket plume impingement on extraterrestrial planetary surfaces. The impact of soil debris was observed to be highly detrimental during NASA's Apollo lunar missions and will pose a threat for any future landings on the Moon, Mars, and other exploration targets.

The innovation developed under this program provides a simulation tool that combines modeling of the diverse disciplines of rocket plume impingement gas dynamics, granular soil material liberation, and soil debris particle kinetics into one unified simulation system. The Unified Flow Solver (UFS) developed by CFDRC enabled the efficient, seamless simulation of mixed continuum and rarefied rocket plume flow utilizing a novel direct numerical simulation technique of the Boltzmann gas dynamics equation. The characteristics of the soil granular material response and modeling of the erosion and liberation processes were enabled through novel first principle-based granular mechanics models developed by the University of Florida specifically for the highly irregularly shaped and co-

hesive lunar regolith material. These tools were integrated into a unique simulation system that accounts for all relevant physics aspects: (1) Modeling of spacecraft rocket plume impingement flow under lunar vacuum environment resulting in a mixed continuum and rarefied flow; (2) Modeling of lunar soil characteristics to capture soil-specific effects of particle size and shape composition, soil layer cohesion and granular flow physics; and (3) Accurate tracking of soil-borne debris particles beginning with aerodynamically driven motion inside the plume to purely ballistic motion in lunar far field conditions.

In the earlier project phase of this innovation, the capabilities of the UFS for mixed continuum and rarefied flow situations were validated and demonstrated for lunar lander rocket plume flow impingement under lunar vacuum conditions. Applications and improvements to the granular flow simulation tools contributed by the University of Florida were tested against Earth environment experimental results. Requirements for developing, validating, and demonstrating this solution environment were clearly identified, and an effective second phase execution plan was

devised. In this phase, the physics models were refined and fully integrated into a production-oriented simulation tool set. Three-dimensional simulations of Apollo Lunar Excursion Module (LEM) and Altair landers (including full-scale lander geometry) established the practical applicability of the UFS simulation approach and its advanced performance level for large-scale realistic problems.

The features and benefits of the developed simulation system enable the screening of landing risk scenarios through: identification of dust and debris transport footprint to protect surrounding assets; prediction of level of erosion and cratering as a function of rocket size and of local soil properties; input into the design of landing pad solidification or paving techniques; minimization of debris environment through optimization of propulsion system layout and landing approach flight path; and designing dust and debris impact mitigation measures such as berms, deflectors, and fences.

This work was done by Peter Liever and Abhijit Tosh of CFD Research Corporation and Jennifer Curtis of the University of Florida for Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13605

Motion Imagery and Robotics Application (MIRA): Standards-Based Robotics

MIRA initial results have demonstrated robotic camera control that is applicable to near-Earth or distant applications.
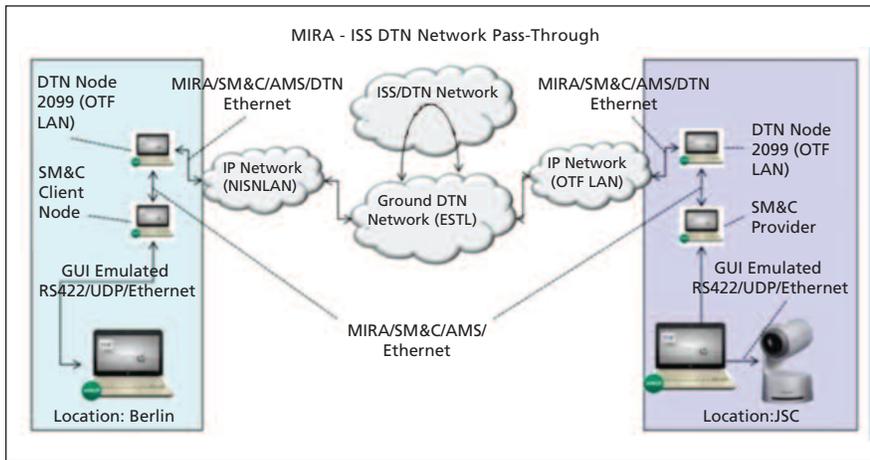
Lyndon B. Johnson Space Center, Houston, Texas

The current Mission Control Center (MCC) is dedicated to the execution of human spaceflight missions. As the future of NASA and human space evolves, it is clear that robotic artifacts will ultimately be integrated and immersed into the human mission. In order to make the evolution and integration as technically capa-

ble at a constrained risk level and with reasonable cost, the robotic elements must adhere to standards that allow not only reuse of previous work, but keep the interfaces stable and reusable.

The MIRA project integrates several telerobotic functions into a powerful Consultative Committee for Space Data

Systems (CCSDS) international standards-based telerobotic service capable of running in an International Space Station (ISS) payload computer. The MIRA goal was to mature, integrate, and demonstrate the MIRA concept (see figure), with Spacecraft Monitoring and Control (SM&C), Asynchronous Mes-

MIRA Architecture

MIRA, SM&C/AMS/DTN standards, the robustness of DTN capability, and remote connectivity to ISS and ground assets (interoperability) will assure the JSC/MCC will be the hub of human, human precursor, and robotic missions where the mission components can be seamlessly integrated with other locations without excessive reconfiguration and integration costs that would render the MCC non-competitive.

The MIRA initial results have demonstrated robotic camera control that is applicable to near-Earth or distant applications where the DTN provides the bridge across the time delay impacts. The MIRA, SM&C/AMS/DTN standards-based status and control system software and protocol could be hardened, and expanded into the next-generation MCC protocol supporting human, robotic, and human-robotic missions. As such, this simple robotic camera prototype is a significant first step in the integration of robotic and human missions into true distant independent building blocks for future missions.

saging Service (AMS), and the Delay Tolerant Network (DTN) standards into a single integrated protocol system.

The ultimate goal of the MIRA project is to develop an application stack for all robotics, even complex ones. It will be capable of status and control of three different cameras on the Exposed Facility (the porch) of the ISS JEM Module from MCC. Each successive phase will add incremental capabilities such as the capability of handling Human Factors and Performance (HFP), and automatic/semiautomatic change detection from imagery of spaceflight vehicles and equip-

ment. In later project phases, it will include ground control of robotic assets over Earth-Moon-Mars time delays, and remote sensing of planetary surfaces and surface navigation.

This project seeks to develop a new standard for robotics such that interoperability with crewed as well as noncrewed elements is provided, assuring cost effective collaboration between NASA and the international space community. The evolution of the proposed standard will be coordinated through the CCSDS International Standards community. The confluence of the

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Particle Filtering for Model-Based Anomaly Detection in Sensor Networks

Experiments on test stand sensor data show successful detection of a known anomaly in the test data.

Stennis Space Center, Mississippi

A novel technique has been developed for anomaly detection of rocket engine test stand (RETS) data. The objective was to develop a system that postprocesses a csv file containing the sensor readings and activities (time-series) from a rocket engine test, and detects any anomalies that might have occurred during the test. The output consists of the names of the sensors that show anomalous behavior, and the start and end time of each anomaly.

In order to reduce the involvement of domain experts significantly, several data-driven approaches have been proposed where models are automatically acquired from the data, thus bypassing the cost and effort of building system

models. Many supervised learning methods can efficiently learn operational and fault models, given large amounts of both nominal and fault data. However, for domains such as RETS data, the amount of anomalous data that is actually available is relatively small, making most supervised learning methods rather ineffective, and in general met with limited success in anomaly detection.

The fundamental problem with existing approaches is that they assume that the data are iid, i.e., independent and identically distributed, which is violated in typical RETS data. None of these techniques naturally exploit the temporal information inherent in time series data

from the sensor networks. There are correlations among the sensor readings, not only at the same time, but also across time. However, these approaches have not explicitly identified and exploited such correlations. Given these limitations of model-free methods, there has been renewed interest in model-based methods, specifically graphical methods that explicitly reason temporally. The Gaussian Mixture Model (GMM) in a Linear Dynamic System approach assumes that the multi-dimensional test data is a mixture of multi-variate Gaussians, and fits a given number of Gaussian clusters with the help of the well-known Expectation Maximization (EM) algorithm. The parameters thus learned