High-Performance Martian Space Radiation Mapping

by Liwen Shih

ABSTRACT—For future safer, sooner, and cheaper deep space missions, we apply high-performance computer techniques to enable better space radiation analysis for the moon, Mars and beyond.

Space radiation is likely to be the ultimate limiting factor for future human deep space exploration. Understanding the space radiation environment is essential for risk assessment of orbit/crew selection and provides the scientific basis of countermeasures for shielding materials (affecting flight weight/cost), radio-protectants, and pharmaceuticals. Every tissue/material/part installed on a space mission requires radiation risk analysis.

HZETRN is the Space Radiation Dosage/Flux Software provided by NASA to simulate high-energy nuclear transport across materials being tested. The HZETRN model has been developed as an accurate scientific model, but the implementation of the model in FORTRAN-77 code using VAX machines is slow and inefficient. Radiation exposure is underestimated by 15-30 percent. HZETRN code is outdated and incompatible with most of the modern compilers/platforms that we tested so far and is broken at times.

In the current HZETRN implementation, space radiation predicting accuracy is low, and three days of Mars data may take up to one day of CPU time to analyze. An essential step toward a more efficient and cost-effective solution to the radiation-shielding problem is the development of accurate, efficient and fast tools for modeling radiation transport. We hope that HZETRN code improvement can benefit the design and engineering of lighter and more cost-effective shielding material for use in NASA spacecraft, *e.g.*, CEV Orion.

A probable key solution to the complex HZETRN computation would be to restructure the computation to match the newly developed resource of a parallel, multithreading network cluster/grid and reconfigurable FPGA (Field Programmable Gate Array) platform. We studied the current execution mode/platform of the NASA space radiation code, to determine the feasibility of finding a high-performance/parallel improvement that will make deep space missions possible.

To modernize and optimize the HZETRN code, we analyzed the code using both static and runtime analysis tools. Specifically, we attacked the HZETRN performance problem from both ends: with top-down parallel thread mapping onto a cluster/grid, and bottom-up bottleneck function routines speeding up with a hardware co-processor performance-accelerator, *e.g.*, FPGA.

We examined multithread code optimization and parallel FPGA options for the major performance bottleneck functions in the source code, including the PHI/interpolation function. Our preliminary FPGA prototypes for bottleneck functions showed up to 325 times speedup. With the newly emerging technology in parallel network clusters/grids and FPGA arrays, it is highly promising that a high-performance improvement of the HZETRN code can be developed that will enhance both speed and accuracy of space radiation analysis.

In support of our space endeavor, our tireless HPC students and alumni volunteers team held weekly meetings throughout 2006 to complete the following tasks:

- Perform HZETRN program flow analysis.
- Study, investigate, and organize HZETRN routines in hypertext and spreadsheet.
- Expand and redesign the FPGA floating point core performance accelerator from 8-bit (in 2005) to a current 32-bit IEEE-754 standard.
- Compare and select hardware FPGA systems with weighted scores.
- Experiment HZETRN with OpenMP on UH TLC^2 parallel clusters.
- Experiment with a parallel Monte Carlo FLUKA code in the UHCL Athena cluster.

In conclusion, we performed HZETRN "diagnosis" and developed a plan for the parallel modernization "treatment" of the code. Support for this effort is still greatly needed. To conduct syntax code thread analysis, we need Data Flow analysis either from the software testing, source code, or algorithm design. To achieve further improvements in such techniques as semantic/application/methodology/algorithm-specific thread mapping optimization, we need a closer collaboration with LaRC nuclear physicists in order to advance a better understanding of how parallel optimization techniques can be applied to the physicists' numerical models.

With the ISSO min-grant and UHCL support, the UHCL team has demonstrated effort to NASA and was granted access to HZETRN1995 in April 2005. NASA LaRC is currently working on establishing a Space Act Agreement (SAA) between NASA and UHCL for a long-term collaboration to enable computer engineers to work with NASA nuclear scientists and engineers to modernize computer applications and to optimize space radiation computation. The SAA was reviewed by the UH System General Counsel and is being revised at NASA Langley. After the SAA is signed, we expect to receive the newest HZETRN2005 code for optimization within two weeks.

The success of applying parallel techniques to enhance both complementing deterministic HZETRN and stochastic FLUKA Monte Carlo radiation transport analysis/simulation code used by NASA scientists will greatly enhance space radiation understanding for safer and cheaper missions sooner. As Earth's ozone depletion continues, space radiation study could lead to dual-use countermeasures that will, in turn, protect human health from radiation/aging effect in general (earth/space), *e.g.*, slowing down cataract development. Other evolving critical *medical* cures, *e.g.*, the higher range-precision proton cancer radiation treatment, are becoming a reality. Radiation shielding study can also lead to safer nuclear energy for the future which in turn can bring about health, peace, economic growth and many emerging technology advancements on Earth.

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Grants, Contracts & Agreements

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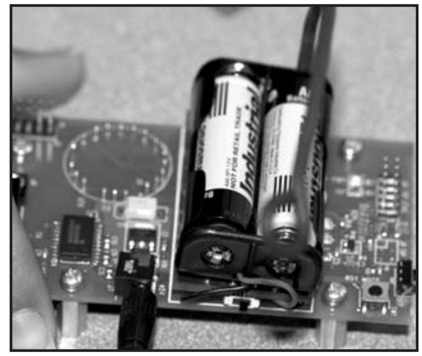
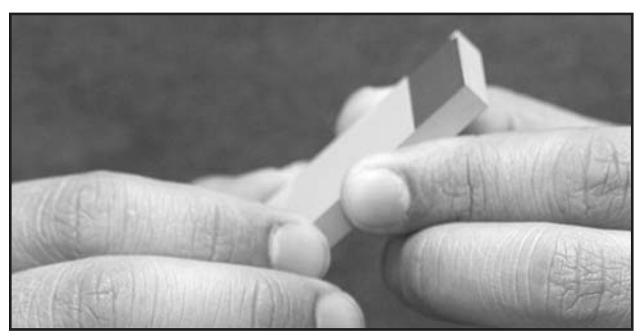
Lab Chips and Board Design



Dr. Dabney's and Dr. Harman's team developed this power supply for a piezoelectric motor causing the rotor to rotate.

This micro-device was developed in Dr. Miller's laboratory for taking *in vitro* measurements of living cell suspensions.

In Dr. Miller's group, Dr. Bukahri developed this fento-ampere amplifier to detect very weak oscillations in cells.



Dr. Bensaoula's team used a brazing furnace to bond a titanium alloy to a ceramic coupon for MCA research.