one could obtain acceptable accuracy from polynomial functions of order no higher than third, complete to second order (see figure). The advantage of using such low-order polynomials is that the interpolation could be performed without need for matrix operations (which would, if needed, add to the computational burden). Approximate-error-indicator quantities, defined on the edges of the simplices, have been derived as guides to whether there is a need to refine the simplices to reduce the errors.

This work was done by Stephen J. Scotti of Langley Research Center. Further information is contained in a TSP (see page 1).
LAR-16297-1

Accumulate-Repeat-Accumulate-Accumulate Codes

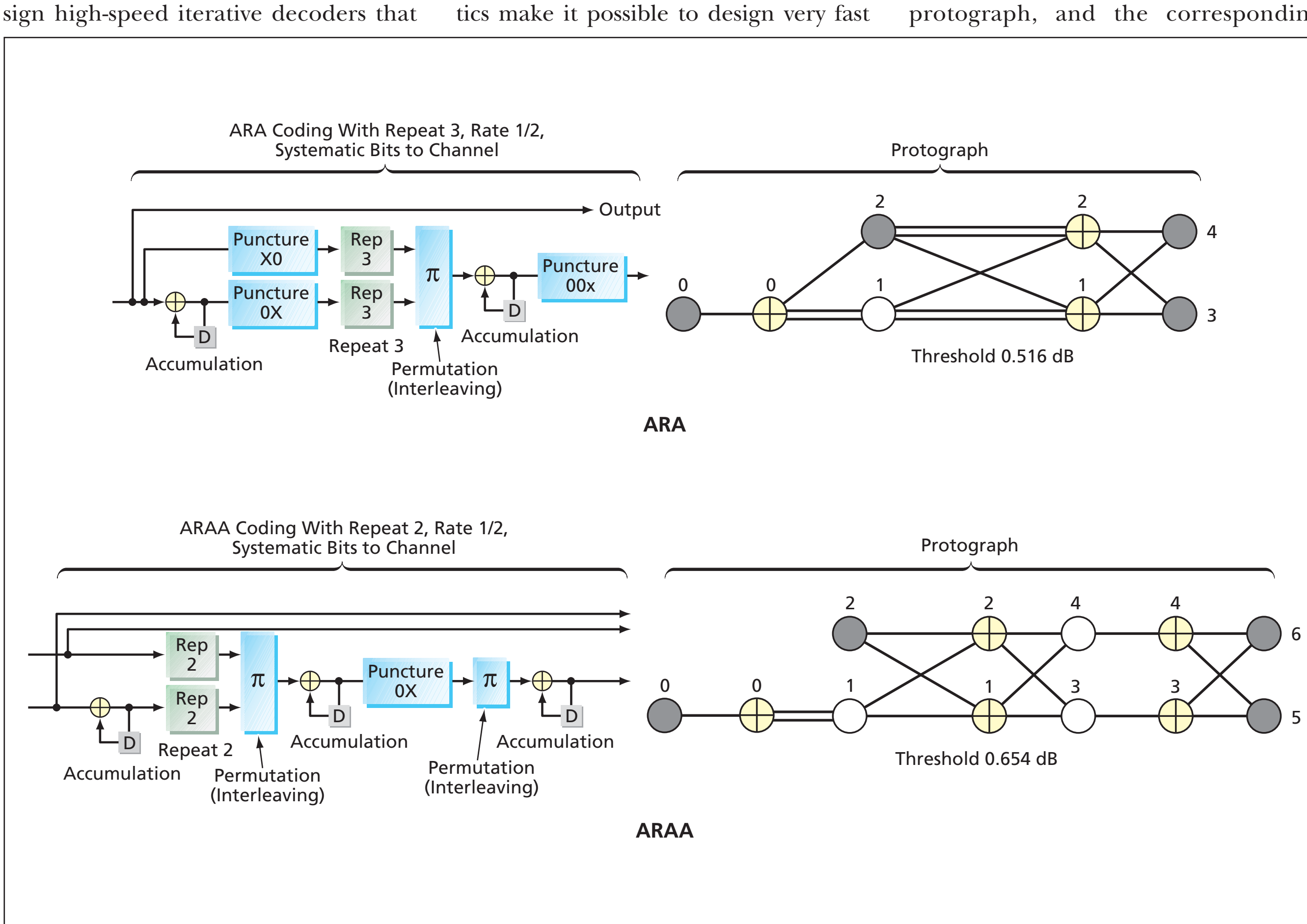
Fast, high-performance coders and decoders could be designed.

NASA's Jet Propulsion Laboratory, Pasadena, California

Accumulate-repeat-accumulate-accumulate (ARAA) codes have been proposed, inspired by the recently proposed accumulate-repeat-accumulate (ARA) codes. These are error-correcting codes suitable for use in a variety of wireless data-communication systems that include noisy channels. ARAA codes can be regarded as serial turbo-like codes or as a subclass of low-density parity-check (LDPC) codes, and, like ARA codes they have projected graph or protograph representations; these characteristics make it possible to design high-speed iterative decoders that utilize belief-propagation algorithms. The objective in proposing ARAA codes as a subclass of ARA codes was to enhance the error-floor performance of ARA codes while maintaining simple encoding structures and low maximum variable node degree.

A rate-1/2 classical repeat-and-accumulate (RA) code has a high threshold (3.01 dB). An ARAA code can be viewed as a preceded RA code with puncturing in concatenation with another accumulation, wherein the preceding is also simply an accumulation; these characteristics make it possible to design very fast encoders. The top part of the figure illustrates the simplest example of the encoding process for a rate-1/2 ARA code, its protograph (filled nodes correspond to transmitted code symbols), and the corresponding decoding threshold of 0.516 dB. Other rate-1/2 ARA examples with maximum variable node degree 5 have thresholds as low as 0.26 dB, which can be compared to the Shannon capacity limit of 0.19 dB.

The bottom part of the figure illustrates a simple example of the encoding process for a rate-1/2 ARAA code, its protograph, and the corresponding



These **Block Diagrams and Protographs** illustrate the similarities and differences between a simple rate-1/2 ARA code and a simple rate-1/2 ARAA code.

threshold of 0.654 dB. The protograph of this code is similar to the ARA-code protograph shown in the top part of the figure, except for the additional accumulator stage and fewer parallel edges. The maximum variable node degree (4) of this ARAA protograph is less than that of the ARA protograph, but the total number of nodes is greater than in the ARA protograph.

Other rate-1/2 ARAA examples with maximum variable node degree 4 (but with larger protographs) can reduce the threshold further. ARAA codes with higher code rates can be obtained by puncturing the output of the middle accumulator: For example, one can obtain thresholds of 1.46 dB and 2.00 dB for rates 2/3 and 3/4, respectively, for punctured versions of the ARAA code represented in the bottom part of the figure. A single fast decoder using a belief-propagation algorithm with depuncturing can be implemented to handle different code rates.

By use of density evolution (a computational-simulation technique for analyzing performances of LDPC codes) on protographs of ARAA codes of maximum variable node degree 4, it has been found that a minimum bit signal-to-noise ratio as low as 0.21 dB above the channel capacity limit can be achieved as the block size goes to infinity. Such a low threshold cannot be achieved by RA, irregular RA (IRA), or unstructured irregular LDPC codes with the same constraint on the maximum variable node degree. Furthermore, by puncturing the accumulators, one can construct families of higher rate ARAA codes with thresholds that stay close to their respective channel capacity thresholds. Results of simulations of iterative decoding have shown that ARAA codes would perform comparably to the best previously known LDPC codes but with very low error floors, even at moderate block sizes.

This work was done by Dariush Divsalar, Samuel Dolinar, and Jeremy Thorpe of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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:

Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-41305, volume and number of this NASA Tech Briefs *issue, and the page number.*

Interface for Physics Simulation Engines

Ames Research Center, Moffett Field, California

DSS-Prototyper is an open-source, real-time 3D virtual environment software that supports design simulation for the new Vision for Space Exploration (VSE). This is a simulation of NASA's proposed Robotic Lunar Exploration Program, second mission (RLEP2). It simulates the Lunar Surface Access Module (LSAM), which is designed to carry up to four astronauts to the lunar surface for durations of a week or longer. This simulation (see figure) shows the virtual vehicle making approaches and landings on a variety of lunar terrains. The physics of the descent engine thrust vector, production of dust, and the dynamics of the suspension are all modeled in this set of simulations.

The RLEP2 simulations are drivable (by keyboard or joystick) virtual rovers with controls for speed and motor torque, and can be articulated into higher or lower centers of gravity (depending on driving hazards) to enable drill placement. Gravity also can be set to lunar, terrestrial, or zero-g.

This software has been used to support NASA's Marshall Space Flight Center in simulations of proposed vehicles for robotically exploring the lunar surface for water ice, and could be used to model all other aspects of the VSE from the Ares launch vehicles and Crew Exploration Vehicle (CEV) to the International Space Station (ISS). This simulator may be installed and operated on any Windows PC with an installed 3D graphics card.

This program was written by Bruce Damer of DigitalSpace Corporation for Ames Research Center. For further information, visit http://www.digitalspace.com/projects/showcase.html.

Inquiries concerning rights for the commercial use of this invention should be addressed to DigitalSpace Corporation at (831) 338-9400. Refer to ARC-15593-1.

RLEP2 lunar rover simulation and **LSAM** human lunar lander simulation using DigitalSpace software.