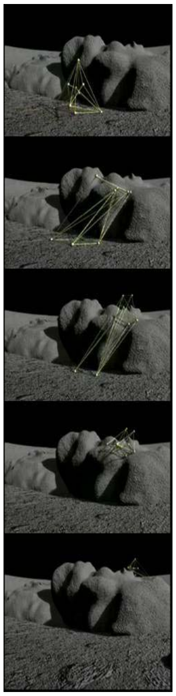
ALI (AUTONOMOUS LUNAR INVESTIGATOR): REVOLUTIONARY APPROACH TO EXPLORING THE MOON WITH ADDRESSABLE RECONFIGURABLE TECHNOLOGY.

P.E. Clark[1], S.A. Curtis[2], M.L. Rilee[1], and S.R. Floyd[2], [1]L3 Communications GSI, 3750 Centerview Drive, Chantilly, VA 20151 (email: pamela.clark@gsfc.nasa.gov), [2]NASA/GSFC, Greenbelt, MD 20771 (u5sac@lepvax.gsfc.nasa.gov).

Addressable Reconfigurable Technology (ART) based structures: Mission Concepts based on Addressable Reconfigurable Technology (ART), originally studied for future ANTS (Autonomous Nanotechnology Swarm) Space Architectures [1,2], are now being developed as rovers for nearer term use in lunar and planetary surface exploration [3,4].

The architecture is based on the reconfigurable tetrahedron as a building block. Tetrahedra are combined to form space-filling networks, shaped for the required function. Basic structural components are highly modular, addressable arrays of robust nodes (tetrahedral apices) from which highly reconfigurable struts (tetrahedral edges), acting as supports or tethers, are efficiently reversibly deployed/stowed, transforming and reshaping the structures as required.

Adaptability of ART components thus limits the need for resources, along with cost, mass, size, bandwidth, power, and, of course, expendables [3,5]. ART systems based on available electromechanical sytems (EMS) (@ 1kg/m2) could support exploration of the lunar surface within the next 10 to 15 years. ART systems based on Nano EMS (NEMS, Super Miniaturized ART or SMART) technology (@ >5g/m2) could perform fully autonomous surveys and operations beyond the reach of human crews two decades from now.



ALI Mission Concept: The Autonomous Lunar Investigator (ALI) is an EMS level mission concept which would allow autonomous in situ exploration of the lunar farside and poles within the next decade. ALI would consist of one or more 12tetrahedral walkers capable of rapid locomotion with the many degrees of freedom necessary to navigate the relatively inaccessible and thus largely unexplored rugged terrains where lunar resources are likely to be found: the farside, the edges of basins, the poles. Because walker locomotion occurs by continuous contraction and extension of struts in a way that optimizes the efficiency of movement across a terrain, a terrain can be crossed as required and probed as curiosity dictates regardless of variability and scale of its relief and roughness [3,5]. ALI rovers would be equipped for autonomous operation in unilluminated terrains, requiring appropriate power generation systems [6] and obstacle location systems [e.g., 7]. Payload and subsystem components would be attached ‘inside’ the tetrahedral nodal network. Reversible struts would allow the structure to be reduced to a minimum strut extension size for shipping to a launch or deployment size.

A wide variety of ALI mission scenarios and payloads could be envisioned. ALI walkers would act as roving field geology teams for sites of particular interest, such as South Aitken Basin, or reconnaissance teams for unexplored regions, gathering and analyzing samples and images on the farside or at high latitudes. A range of spectrometers, including neutron, gamma-ray, X-ray, and near IR, with active sources as required for operation in unilluminated areas, could determine elemental, mineral, and rock type abundances in probed or collected samples, in conjunction with sounders to confirm the presence of ice below the surface, and mass spectrometers to measure sample isotope ratios and volatile abundances. In this way, not only would detailed determination of lunar history, origin and age be possible, but the identification of sites with resources useful for permanent bases, including water and high Ti glass.

Current Developments in ART Rovers: A prototype of a single Tetrahedral Walker has already been constructed and demonstrated, and prototypes of a 4Tetrahedral Walker, that tests the concept of a centralized payload node, and a 12Tetrahedral walker are currently under development [3,5].

The ART Design utilizes Electro-Mechanical components at present. Each easily machinable aluminum segmented telescoping strut is attached at two nodes to allow movement over a wide range of angles. This material is relatively lightweight and easily machinable, yet strong enough to hold the weight of the structure. Struts are reversibly wound and unwound using a battery-operated high torque motor driven string pulley mechanism. Command and control is still relatively primitive: either manually driven or through preprogrammed sequencing. Nodes contain the power and control systems. Struts are deployed to shift the center of mass, allowing a single tetrahedron to simply topple over in alternating directions. A multi-tetrahedral structure, with more degrees of freedom, approaches continuous, amoeboid movement.

A key to performance of such a system is efficiently designed mechanisms [5]. As more nodes are interconnected in tetrahedral networks, a skeletal muscular framework with a high degree of freedom emerges. The ability to control the timing and extent of strut deployment allows control of the scale and gait of a walker. A single tetrahedron, like the prototype we are currently building, rocks from side to side as it moves forward. Put an additional strut at each node and divide that tetrahedron into 4 parts (like the 4Tet we are proposing to field test), and an inner node can be used for attaching of a payload and shifting the center of mass more easily. In a 12Tet model, motion is far more continuous. Clear amoeboid-like movement can be observed for very rough surface, more 'natural' than wheels, effectively allowing 'flow' across a surface or into a particular morphological form. For a very smooth surface, or for 'storage' the minimum surface area spheroid, rolling across the ground, could be effective. Uphill climb or slipping through narrow openings could require a more snakelike morphology. When surmounting obstacles, the rover could either change its scale, growing in size, or use a climbing motion, pulling itself over using facets on the obstacle itself as 'toe holds'.

More autonomous command and control systems which will be required for autonomous navigation the coordination of the greater number of nodes in a multi-tetrahedral rover, are currently under development as well.

ALI Autonomous Navigation and Control: Control is a key challenge in realizing a rover that can operate in highly irregular terrain filled with rock piles or sheer cliffs, where locomotion requires an intimate blending of dynamics and statics, i.e. pushing, bracing, and balancing to make progress. Most means of locomotion try to "finesse" the situation by somehow glossing over the complexity of the terrain: typically, rovers have featured wheels or legs that are larger than the terrain scale sizes, or locomotion that is slow to allow expert computer systems time to figure out where to go next. The 12 TET rover will become a moving part of the terrain, its LIDAR-based vision system [e.g., 7] providing volumetric information about its surroundings. With information about the geometry of its environment as well as information about its own geometry, the 12 TET places itself within and moves through its environment.

For the shortest timescales, the 12 TET is essentially a behavior-based nonlinear dynamical system. A Neural Basis Function (NBF) software architecture is used to define, control, and organize the network of actuators responsible for 12 TET motion. NBFs are composed of multiple high- and low-level control systems within an Evolvable Neural Interface (ENI) which acts as an active communication medium between the control elements. The high-level components generally rely on a more symbolic approach to control and may involve planning and schedule and other heuristic control. Low-level components are typically directly linked to system actuators and sensors and generally provide a more reactive approach. Separate behaviors of the 12 TET are typically instantiated as separate NBFs: to add new behaviors the aim is to simply link the EN of the new behavior into the system and then allow the ENIs to adapt the old and new components to each other. In this way, behaviors may be added together in a way analogous to the basis functions of mathematical physics. The NBFs for the 12 TET are built on what we have learned applying the NBF architecture to a control system for autonomous rendezvous and capture of a chaotically tumbling target, a problem inspired by the Hubble Space Telescope Rescue mission [4,5].

ALI Power Requirements: Efficient power generation is an enabling technology for the ALI concept as well as other ART applications architecture applications, which require watts to milliwatts of power from minimal mass [1,5]. Small radioisotope power systems (RPS) [e.g., 8] generating watts to milliwatts of power based on this technology would allow vehicles to operate in areas of minimal insolation over long periods of time, in unilluminated hemispheres of terrestrial planets. These tiny MEMS batteries are small in mass and could easily be embedded in ART structures. However they individually generate very small increments of power using thermoelectric or electromechanical conversion mechanisms with only few percent efficiency. Methods proposed by Sam Floyd for improving the thermal output and relatively inefficient thermoelectric conversion rate by at least half an order of magnitude are highly desirable and necessary for more advanced ANTS applications.

References: [1] Curtis et al (2000) 51st Intl Aeronautical Congress, Vancouver, IAC Proc, #IAF-00-Q.5.08; [2] http://ants.gsfc.nasa.gov (1/1/2005); [3] Clark et al (2004) 55th Intl Aeronautical Congress, Vancouver, IAC Proc, #IAC-04-IAA.3.8.1.08; [4] Rilee et al (2004) 55th Intl Aeronautical Congress, Vancouver, IAC Proc, #IAC-04-I.4.08; [5] Clark et al (2004) AIAA 1st Intelligent Systems Technical Conference, Chicago, ISTC Proc, Session 29-IS-13: ANTS, #29-IS-13-02; [6] Clark et al (2005) STAIF Proc, Albuquerque, NM, (SRP Concepts and Applications II); [7] Ye and Borenstein (2004) IEEE Trans, Robotics, 20, 913-921; [8] Blanchard and Lal (2004) http://www.spectrum.ieee.org/WEBONLY/publicfeature/sep04/0904nuc.html (10/01/04).