Title of Investigation:

Reconfigurable Tetrahedral Walker

Principal Investigator:

Dr. Steven A. Curtis (Code 695)

Other In-house Members of Team:

Dr. Cynthia Y. Cheung (Code 695) and Gary L. Brown (Code 544)

Other External Collaborators:

None

Initiation Year:

FY 2004

Aggregate Amount of Funding Authorized in FY 2003 and Earlier Years:

$0

Funding Authorized for FY 2004:

$35,000

Actual or Expected Expenditure of FY 2004 Funding:

In-house: $20,000 for Code 547 fabrication and $15,000 for Tetrahedral Walker parts

Status of Investigation at End of FY 2004):

Transitioned to FY 2005 and FY 2006 IRAD funding for tetrahedral robotics development.

Expected Completion Date:

September 2006

Figure 1. The 4-TET in motion

Purpose of Investigation:

The goal of this investigation is to develop a conceptual design and electro-mechanical control scheme for the 4-Tetrahedra Walker (TET Walker), a robot that moves by rolling. This is part of a three-tiered effort to develop a new kind of structural material that can change its form to improve its function or adapt better to its environment. The material is called SMART, which stands for Super Miniaturized Addressable Reconfigurable Technology. SMART matter is a parallel system of interconnecting reconfigurable nodes made of macroscopic electromechanical systems (EMS), micro- (MEMS), or nano-electromechanical systems (NEMS), depending on the application. This highly integrated, three-dimensional mesh of actuators and structural elements is composed of nodes that are addressable as are pixels on an LCD screen. It is an undifferentiated architecture that can reconfigure into a variety of functions without the need for specialized appendages such as legs or arms. SMART has multiple near-term applications—from rovers on planetary surfaces to specialized attachments for robotic servicing of the Hubble Space Telescope. It also can be used as a gossamer-like reconfigurable structural frame for space payloads, providing small launch volume and structural stability for large space structures/apertures.

The fundamental unit of SMART material, a reconfigurable tetrahedron, is already being prototyped through a joint effort involving Code 695 and Code 544. This minimal design is sufficient to demonstrate the advantage of a mobile platform that has no top or bottom and no back or front. Therefore, it cannot fall down and not get up. The walker can stretch or contract to conform to terrain, going where no wheels dare to go. The result of our efforts is to take the next step and design and develop a prototype four-strut walker as a mobile platform to carry a payload in the central node is presented here.

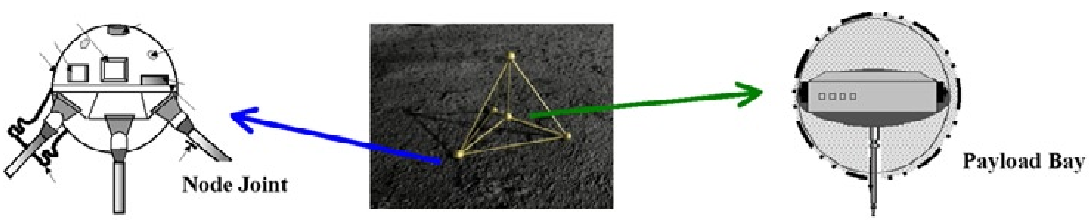

Figure 2. 4-TET conceptual design

Accomplishments to Date:

We have just demonstrated the single walking tetrahedron prototype, which acts as a "proof of concept" for the strut-deployment mechanism. We have developed a preliminary conceptual design of a 4-TET Walker that carries an astrobiology payload in its central node for a proposed Astrobiology Science and Technology for Exploring Planets (ASTEP) field campaign in Iceland. The design includes: (1) Node joints to accommodate struts, control electronics, and actuation mechanisms; (2) Node shroud to prevent debris from entering joint; (3) Both active and passive control options for the payload attachments; (4) A payload bay with a double-sliding sphere enclosure. The outer shell provides a protective cover and the inner shell is self-righting with weights at the bottom. An opening at the bottom of the sphere allows the deployment of a science probe for in-situ data acquisition; and (5) Preliminary 4-TET Walker remote control electronics.

Based on lessons learned in building the single tetrahedron prototype, we proceeded to build a 12-tetrahedra. in FY 2005 using second-generation struts. Because the struts are modular, we plan to build a prototype 4-TET Walker in FY 2006, using these second-generation struts with a breadboard payload in its interior. This will demonstrate the optimal placement of the payload by controlling the interior struts. Below is a picture of a 1-tetrahedron using the second-generation struts, which was demonstrated in December 2005.

Reports, Journal Articles, Presentations:

M.L. Rilee, S.A. Curtis, W.F. Truszkowski, P.E. Clark, C.Y. Cheung, “From Buses to Bodies: SMART Matter for Space Systems Applications,” Presented at the 55TH IAC, Vancouver, Canada, 2004.

P.E. Clark, M.L. Rilee, S.A. Curtis, W.F. Truszkowski, C.Y. Cheung, G.C. Marr, M. Rudisill, “BEES for ANTS: Biologically Inspired Engineering for Exploration Systems Concepts as Applied to Autonomous NanoTechnology Swarm Architecture,” Presented at ISTC/AIAA, Chicago, 2004.

M.L. Rilee, S.A. Curtis, C.Y.Cheung, J.E. Dorband, “Evolving a Self-organizing Neuromechanical System for Self-Healing Aerospace Structures, Presented at CANEUS, AIAA, Monterey, 2004.

C.Y. Cheung, S.A. Curtis, P. S. Yeh, M.L. Rilee, P.E. Clark, W.F. Truszkowski, “Intelligent Systems in the Evolvable ANTS Architecture, Presentation at ISTC, AIAA, Chicago, 2004.

P.E. Clark, S.R. Floyd, S.A. Curtis, M.L. Rilee, “SMART Power for ANTS Systems,” Presented at STAIF, Albuquerque, 2005,

Planned Future Work:

5–10 years: Addressable Reconfigurable Technology (ART) using conventional electromechanical systems and metal struts, real density < 1 kg/m^2 (Walking Multi-Tetrahedra)

10–15 years: Micro Addressable Reconfigurable Technology (MART) using MEMS and carbon composite struts, areal density < 100 g/m^2 (Lunar Lander, Amorphous Rover, Antenna)

20–25 years: SMART using NEMS and carbon nanotube struts, areal density < 10 g/m^2 (Solar Sails, Fully Autonomous Pico Spacecraft and Manufacturing, Self-Repairing Structures)

Additional Related Accomplishments:

1. Demonstration of single walking tetrahedron prototype, which acts as a "proof of concept" for the strut-deployment mechanism
2. Simulation of Addressable Reconfigurable Technology (ART) structures at EMS (simple tetrahedra), MEMS (multiple tetrahedra), and NEMS (continuous space filling structures) levels
3. Conceptual design for 12-Tetrahedral Walker

Key Points Summary:

Project's innovative features: The 4-TET Walker is a first application of the reconfigurable tetrahedral-based robotics as a mobile science platform. It has no top or bottom, no back or front, and therefore, cannot fall down and not get up. The 4-TET Walker can stretch or contract to conform to terrain, and is ideally suited for exploring rugged regions on planetary surfaces.

Potential payoff to Goddard/NASA: NASA's exploration initiative will benefit from the development of versatile robotics, which offer low-cost failsafe redundancy. Goddard will benefit because this investment will put Goddard at the forefront of a revolutionary rover architecture that is ideally suited for rugged lunar highlands. The effort will develop unique in-house skills, particularly in the construction and operation of robotic electro-mechanical systems, control and power engineering, complex reconfigurable systems, and MEMS planetary instruments and sensors.

The criteria for success: By the end of the performance period, we will demonstrate the operation of the 4-TET Walker as a mobile science platform.

Technical risk factors: Technological advances in materials science and intelligent system research may affect the availability of cost-effective, tetrahedral-based ART (Addressable Reconfigurable Technology) and MART (MEMS ART) structures and controllers for full use in the exploration initiative.