The 2009 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 11-15, 2009 St. Louis, USA

A Small, Autonomous, Agile Robot with an On-board, Neurobiologically-based Control System

William A. Lewinger, *Member, IEEE* and Roger D. Quinn, *Member, IEEE*

Abstract—**For decades, insects have been a valuable source of inspiration for mechanical and control designs of legged robots. Anatomical and behavioral studies of insects such as cockroaches, stick insects and locusts have inspired the development of many robots. However, their control systems had to be engineered based upon behavioral studies and control hypotheses rather than neurobiology. Recent insect neurobiological discoveries now make it possible to control the legs of robots with a network found to control the legs of stick insects. In previous work this network we have dubbed SCASM (Sensory-Coupled Action Switching Modules) was shown coordinating the joints of a robot leg and adapting its normal leg cycle to irregularities in the terrain. We also showed that the SCASM network can be implemented effectively on a simple micro-controller with little computational power. This video describes additional sensory connections that, when added to SCASM, generate elevator and searching reflexes. We also show for the first time an autonomous hexapod robot walking over irregular terrain using a SCASM network to control each of its six legs and a Cruse type network to control its gait using only on-board, simple micro-controllers.**

I. INTRODUCTION

INSECTS have influenced the designs and controlled behaviors of hexapod robots in various degrees for decades. Many robots have been designed with a generic insect configuration while others are more strongly influenced by an insect's morphology such as TUM [13], a stick insect robot, and Robot III [12], a cockroach robot. The wealth of insect behavioral data has also been used to great advantage. In fact, the well-known Cruse insect gait generation network [4] is based upon decades of stick insect behavioral experiments. However, the actual thoracic circuits that coordinate legs and gaits were not known, thus insect-inspired robot controllers have been engineered based upon hypotheses about neurobiology, simple models and behavioral studies. Brooks developed finite-state machines to control Genghis [1] and Hannibal [8], Robot I [6] used a Cruse gait controller and standard inverse kinematics for leg control, Robot II [7], TUM [13], the Lauron series [9], Scorpion [3], and BILL-Ant-p [10] could walk on irregular terrain with a similar system and the addition of a number of insect reflex behaviors. Even Walknet [15] used by the Tarry series [2] is based more on stick insect behavioral studies than neurobiology. There are many others robots too numerous to mention in a brief paper that use engineered controllers more or less inspired by behavioral studies.

As impressive as some of these robots have been shown to be, they have two limitations. First, they are not as agile as their insect models and second their control systems are complex and require intensive numerical computations. Typically, robots such as these have the ability to dynamically sense their environment, alter their gait, and navigate irregular terrain, but they require the computation ability of a computer, which requires a great deal of battery power to operate.

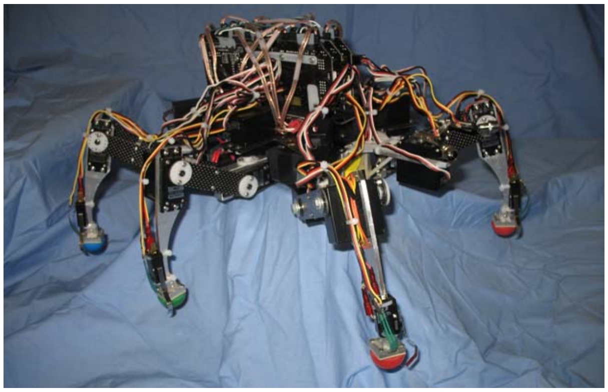

Fig. 1. BILL-Ant-a (Biologically-Inspired Legged Locomotion Ant-Autonomous) walks autonomously on irregular terrain using SCASM leg control implemented using low-computation-capable microcontrollers.

Fortunately, many years of integrated neurobiological and behavioral studies of stick insects have resulted in an elegant intra-leg control network, which is both powerful and computationally simple [5]. In previous work it was shown that this network we have dubbed SCASM (Sensory Coupled Action Switching Modules) can coordinate the joints of a robot leg and modify the movement of the leg to adapt its normal cycle to irregularities in the terrain [11, 14]. We have also shown that the SCASM network can be implemented effectively on a simple micro-controller that is multiple orders of magnitude less capable than modern computers [11]. In this video we demonstrate that additional sensory connections added to SCASM can generate elevator and searching reflexes and descending commands from a higher center can modulate SCASM to cause turning. We also show that an autonomous hexapod robot, BILL-Ant-a (Biologically-Inspired Legged Locomotion Ant –

Manuscript received March 1, 2009. This work was supported in part by NSF IGERT Training Grant DGE 9972747 and Eglin AFB Grant FA9550-07-1-0149.

W. A. Lewinger is with the Electrical Engineering and Computer Science Department at Case Western Reserve University, Cleveland, OH 44017 USA (e-mail: william.lewinger@case.edu).

R. D. Quinn is with the Mechanical and Aerospace Engineering Department at Case Western Reserve University, Cleveland, OH 44017 USA (e-mail: rdq@case.edu).

978-1-4244-3804-4/09/$25.00 ©2009 IEEE

autonomous), can walk over irregular terrain while seeking goals using a SCASM network to control each of its six legs and a Cruse type network to control its gait – all implemented on onboard simple micro-controllers (Fig. 1).

II. NARRATION

Insects are frequently used as the inspiration for legged robot designs because of their ability to easily navigate difficult and uneven terrain. However, giving robots the ability to sense and react to their terrain can require large amounts of computation ability. Large robots have enough size to carry computers with them, but small, capable robots typically have off-board control systems and can move quite slowly. These factors can greatly limit their mobility.

A computationally simple leg joint control method [SCASM] has been observed in stick insects that can be easily implemented for use in small robots with low computation capabilities. This method determines the direction and speed of each leg joint to develop an emergent walking motion. Each joint's direction is determined by sharing sensory information with other joints in the leg.

Modifying the setpoints that determine when the joints change direction and the muscle activation levels that determine joint speeds can allow the foot path to move in different directions. This provides the ability for the robot to turn.

Here we see a two-legged test platform following a light source. The left and right legs step to the left of their forward paths by modifying the joint direction transition setpoints and muscle activation levels. This causes the platform to move to the left, toward the light source.

A computationally simple, speed-dependent emergent gait method [BILL-LEGS] has also been developed to coordinate movements between the legs. This allows a continuum of gaits to form using trivial equations that can be performed by small hexapod robots using rudimentary, on-board microcontrollers instead of off-board computers.

By adding simple obstacle collision sensory paths to the leg control method, an elevator reflex behavior can be created that allows the robot to step over surmountable obstructions. For this robot, obstacle detection has been implemented by means of a contact switch near each foot.

Similarly, the addition of a joint angle sensing signal can warn the robot of holes. This new sensory path allows the robot to use a searching reflex to step beyond holes or gaps and find solid terrain on the other side.

The control of each leg is handled by a low-computation-capable microcontroller. These devices are connected to one another so that they can share leg position and state information in order for coordinated gaits to emerge. While many orders of magnitude less capable than full computers, these trivial microcontrollers allow this version of the robot to move almost 8 times faster than its off-board computer-controlled counterpart due to the lack of the communications bottleneck in the control tether.

This research has shown that biologically-based intra- and inter- leg coordination can be implemented with on-board, low-computation-capable microcontrollers such that small, legged robots can have a high level of mobile autonomy, while still possessing the dynamic walking ability necessary to move toward goals while navigating uneven terrain.

REFERENCES

[1] R. A. Brooks, “A Robot That Walks; Emergent Behaviors from a Carefully Evolved Network” Technical Report, MIT AI Lab Memo 1091, Cambridge, MA, USA February 1989.

[2] A. Buschmann, "Home of Tarry I & II: Design of the Walking Machine Tarry II," World Wide Web: http://www.tarry.de, March 2000.

[3] S. Colombano, F. Kirchner, D. Spenneberg, and J. Hanratty, “Exploration of Planetary Terrains with a Legged Robot as a Scout Adjunct to a Rover,” in AIAA Space 2004 Conference and Exhibit, September 28-30, 2004, San Diego (CA), USA.

[4] H. Cruse, "What Mechanisms Coordinate Leg Movement in Walking Arthropods," *Trends in Neurosciences*, vol. 13, pp. 15-21, 1990.

[5] Ö. Ekeberg, M. Blümel and A. Büschges, "Dynamic Simulation of Insect Walking", Arthropod structure & development **33** 287 (214 pages), 2004.

[6] K. S. Espenschied, R. D. Quinn, H. J. Chiel, and R. D. Beer, "Leg Coordination Mechanisms in Stick Insect Applied to Hexapod Robot Locomotion," Adaptive Behavior, Vol. 1, No. 4, pp. 455-468, 1993.

[7] K. S. Espenschied, R. D. Quinn, R. D. Beer and H. J. Chiel, "Biologically Based Distributed Control and Local Reflexes Improve Rough Terrain Locomotion in a Hexapod Robot", Robotics and autonomous systems **18** 59 (56 pages), 1996.

[8] C. Ferrell, “Fault Recognition and Fault Tolerance of an Autonomous Robot,” in *Adaptive Behavior*, Vol. 2, No. 4, pp. 375-298, 1994.

[9] B. Gassmann, K.-U. Scholl and K. Berns, *Behavior Control of Lauron III for Walking in Unstructured Terrain*, Intl. Conference on Climbing and Walking Robots (CLAWAR '01), 2001, 651-658.

[10] W. A. Lewinger, M. S. Branicky and R. D. Quinn, *Insect-Inspired, Actively Compliant Robotic Hexapod*, International Conference on Climbing and Walking Robots (CLAWAR), 2005.

[11] W.A. Lewinger, B.L. Rutter, M. Blümel, A. Büschges and R.D. Quinn, “Sensory Coupled Action Switching Modules generate robust, adaptive stepping in legged robots,” in *Proceedings of the International Conference on Climbing and Walking Robots* (CLAWAR’06), pp. 661–671, Brussels, Belgium, Sept 12–14, 2006.

[12] G. M. Nelson, R. D. Quinn, R. J. Bachmann, W. C. Flannigan, R. E. Ritzmann, and J. T. Watson, “Design and Simulation of a Cockroach-like Hexapod Robot,” in *Proceedings of the 1997 IEEE International Conference on Robotics and Automation* (ICRA ’97), Albuquerque, NM, April 22-24, 1997.

[13] F. Pfeiffer, H. J. Weidemann and J. Eltze, "The TUM Walking Machine. - in: Intelligent Automation and Soft Computing," *Trends in Research, Development and Applications*, vol. 2, TSI Press, 1994, 167-174.

[14] B.L. Rutter, W.A. Lewinger, M. Blümel, A. Büschges, and R.D. Quinn. (2007) “Simple Muscle Models Regularize Motion in a Robotic Leg with Neurally-Based Step Generation,” IEEE International Conference on Robotics and Automation (ICRA'07) Proceedings, Roma, Italy, April 10-14, 2007.

[15] J. Schmitz, J. Dean, T. Kindermann, M. Schumm, and H. Cruse, “A Biologically Inspired Controller for Hexapod Walking: Simple Solutions by Exploiting Physical Properties,” in *The Biological Bulletin,* **200**:195-200. April 2001.