USC/ISI Polymorphic Robotics Laboratory

SELF-CONFIGURABLE AND ADAPTABLE ROBOTS

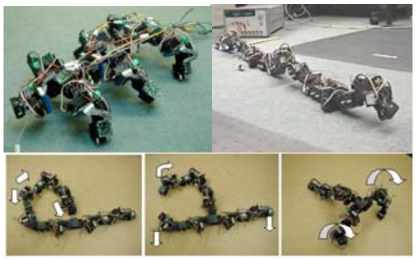
I. THE POLYMORPHIC ROBOTICS LAB

Over the last 30 years, the University of Southern California's Information Sciences Institute (ISI) has emerged as one of the world's leading research centers in the fields of computer science and information technology. It would be impossible to cover the breadth of their research in a short article like this, so we focus on a very small laboratory that is making big news in the robotics world.

The ISI Polymorphic Robotics Laboratory (PRL) is one of six laboratories associated with the USC School of Engineering's Center for Robotics and Embedded Systems. Led by Wei-Min Shen and Peter Will, this laboratory is a leader in self-reconfigurable and adaptive robot research, with projects including self-assembly for Space Solar Power Systems (SOLAR), the self-reconfigurable robot CONRO, the robot soccer team DREAMTEAM, the Intelligent Motion Surface, and the indoor navigation robot YODA.

PRL researchers develop modular hardware systems and teams of independently-controlled autonomous agents that work in synergy. Their robot soccer team was ranked #1 in the 1997 RoboCup contest due to their speed and quick reactions. The lab is currently organizing a new team.

In this article we highlight two related projects that are particularly good examples of some of the novel ideas being generated by this laboratory.



CONRO units can combine in many different configurations

II. MODULAR ROBOTS GROW BY MELDING

Real-life "Transformer" robots can automatically reconfigure as needed for different applications.

PRL researchers have designed robotic units that can knit themselves together in a variety of ways, automatically taking on different behaviors depending on their positions. Identical modular units can autonomously look for and find each other, link themselves to one another and then, when united, work effectively as a single unified whole.

Metamorphing robots − known as CONROs, for CONfigurable RObots − may soon be worming their way through small crevices in earthquake debris or at a fire scene. Once inside, the tail of the worm could disconnect and reattach as legs. Each CONRO unit could be equipped with a different sensor, speaker, or even be able to deliver doses of medicine. Microscopic versions might work their way into keyholes and unlock doors, or even assemble inside the body to form surgical instruments.

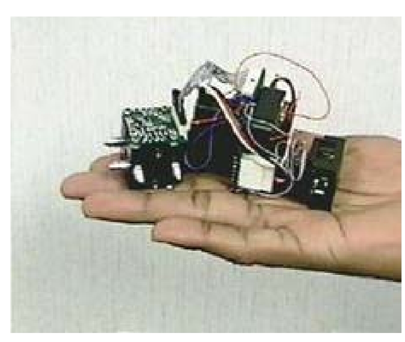
The prototype CONRO units are about three inches long, consisting of a few small electric motors, a processing unit, and an active end that can move back and forth and up and down. This end has plugs on three sides that fit into receptacles on the front ends of other devices.

Separated units communicate using infrared signals, maneuvering their coupling units into a lock in cooperative, coordinated fashion. They use very simple messages called "hormones" by analogy to biological chemical messengers. In much the same way, CONRO's hormones are passed between nearest neighbors so their main data is type and locality.

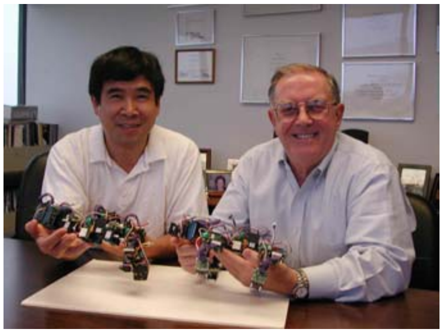
Shen said that such software allows "bifurcation, unification, and behavior shifting" by the modules. The units can unite themselves into larger wholes, or divide themselves up into smaller ones. "If a six-unit snake splits in half," explained Shen, "you get two smaller, three-unit snakes that function as the larger one did."

"Behavior shifting" means that identical individual units can exhibit different behavior according to their position in the assembly.

More than a year ago, the working group succeeded in the seemingly modest step of having a snake of six robots find and link to its own tail to form a ring. In another configuration, with six units linked as legs to a seventh and eighth units which serve as a body, an insect-like creature emerges which can walk on six legs, moving three at a time.
A recent development is a snake that reconstructs itself into a T-shaped assembly that "flies" or "swims" by moving the sides of the T crossbar like wings or fins.



One CONRO unit.



Wei-Min Shen, left, and Peter Will, holding hormone software controlled CONRO modules. They recently received the Phi Kappa Phi Faculty Recognition award for this work.

Peter Will, who in 1990 received the robotics profession's highest honor, the International Engelberger Prize, directs the CONRO project. He notes that creation of truly capable metamorphing robots will require improvements in many areas, including the development of chips that do more with less power.

ISI's Polymorphic Robots Laboratory is not the only site doing research on modular, self-assembling robots. Xerox Parc has long been working on a parallel project, called PolyBots.

CONRO's reconfiguration behaviors are autonomous and controlled in a totally distributed manner, Shen says, which distinguishes CONRO from many existing chain-typed self-reconfigurable robots like those from Xerox Parc.

The demands on software to achieve this performance are daunting. "The robots must recognize the conditions that dictate a change in form, must determine the proper new form to assume, and be able to do so quickly and efficiently under confused, real world conditions." he said. "These are major challenges. Nevertheless, the rewards for successful implementation of this technology make a vigorous effort worthwhile, and we are cheered by the successes we have so far achieved."

III. ROBOT SPACE COWBOYS

A unique University of Southern California design for self-organizing robots controlled by "hormonal" software is moving toward space.

At the Robosphere 2002 conference held at the NASA Ames Research Center in Silicon Valley November 14-15, Wei-Min Shen presented an overview of an audacious project to have pieces of the proposed half-mile-long Space Solar Power System satellite assemble themselves without the help of astronauts.

Shen and Will's new SOLAR space station proposal, funded by a consortium including NASA, the NSF, and the Electric Power Research Institute (EPRI), proposes to use the CONRO architecture on a gigantic scale.

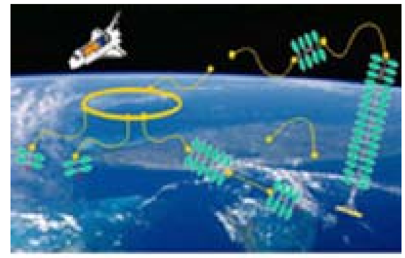
They propose a self-assembling space station consisting of two species of robotic devices, both controlled by the same software.

One species will be the parts that actually make up the station: solar power units, including necessary utility conduits. Each of these will have a microprocessor running hormonal software. Sets of contiguous units will, once released into space, arrange themselves into the desired configuration.

When these subassemblies are ready, they will signal and alert a second species of robot, the "free-flying intelligent fiber rope matchmaker units," or *whips*.

Whips consist of two modular robot units connected by a long connector line that can shorten or lengthen at the direction of the software. They will also have solar-powered rockets, enabling them to move in space, GPS sensors to find their position, communicators, and connectors.

When a completed subassembly signals, a whip will maneuver toward it, lock on, and wait for a call from a second assembly. The free end of the whip will fly to the second assembly and lock on to it. Then the whip pulls the parts together by shortening the connector line. Once the two parts are mated, the whip unit can fly off to find other parts to assemble. The design, said Will, combines the advantages of free-flying and tethered systems.



Schematic diagram of architecture of self-assembling solar power satellite. Seeker "whip" units, powered at both ends, listen for signals from subassemblies, find them, and pull them together.

In the laboratory, Shen and Will have modeled the concept in two-dimensional form, working with an air-hockey table. The prototype whips find parts by sensing their infrared signals, maneuver next to them using built-in fans, mechanically lock on, and pull units together using a motorized cable.

"This will give both the hardware and software a realistic test," said Shen. Researcher Harshit Suri has built a first prototype unit.

Shen, Will, and ISI collaborator Behnam Salemi published a detailed paper, "Hormone-Inspired Adaptive Communi-
cation and Distributed Control for CONRO Self-Reconfigurable Robots," in *IEEE Transactions on Robotics and Automation* on October, 2002. They have recently applied for a U.S. patent on the technology.

Working with Shen and Will in the field of space assembly are two faculty members from the USC School of Engineering: Berokh Khoshnevis of the department of industrial and systems engineering; and George Bekey, of the department of computer science. Along with Suri and Salemi, Yusuf Akteskan is working on the space system project.

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