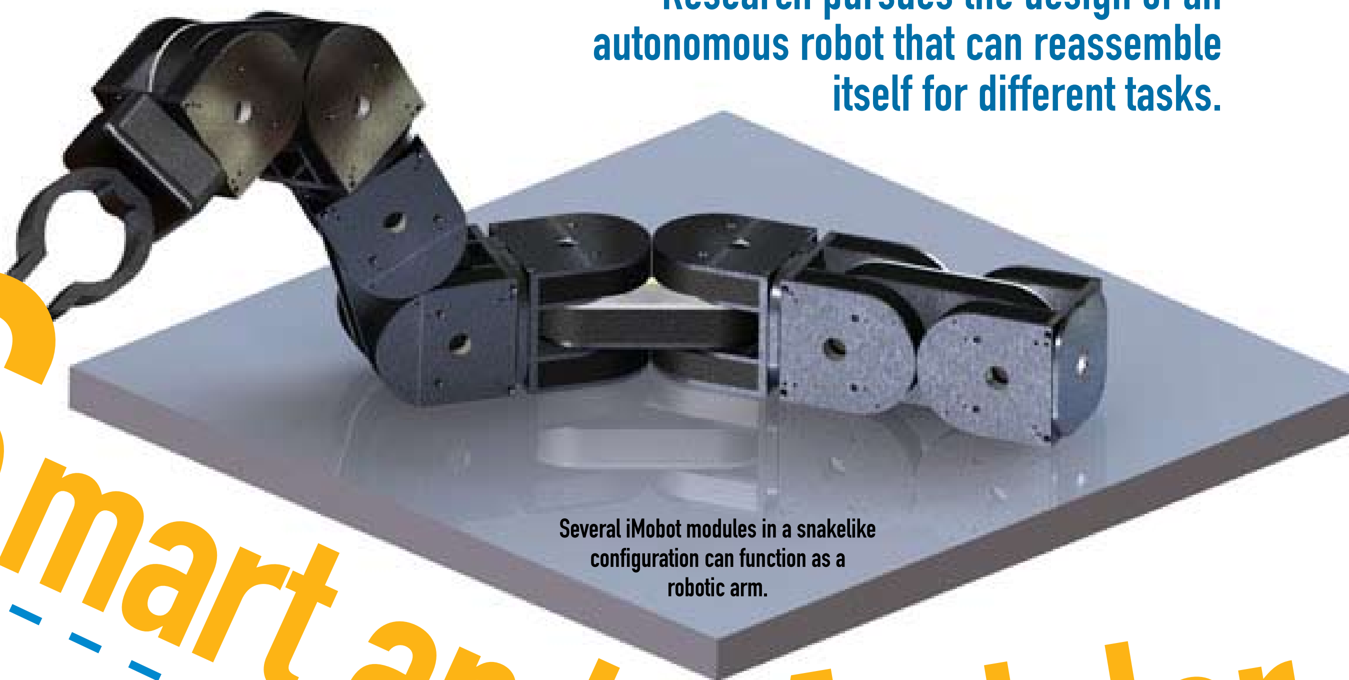
**Research pursues the design of an autonomous robot that can reassemble itself for different tasks.**



Several iMobot modules in a snakelike configuration can function as a robotic arm.

# Smart and Modular

BY HARRY H. CHENG, GRAHAM RYLAND, DAVID KO, KEVIN GUCWA, AND STEPHEN NESTINGER

Robots make good workers. They perform a routine task time after time with the same precision until they wear out. They are not distracted. Moods do not alter their performance. They can work around the clock. They do not take sick days or vacation.

But they are also not very adaptable.

Traditional robotic designs typically tailor a robot for a specific task. However, in certain situations, there is a need for a multi-functional, adaptable robotic system with autonomic attributes which can be used in an improvisational manner.

Modular robotics research arose out of a need for these more general multi-purpose

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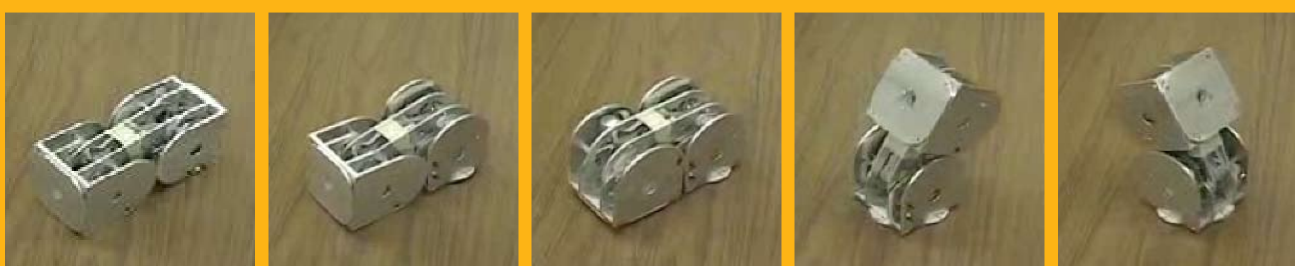
robotic systems. Modular robots are composed of multiple, linked modules. Although individual modules can move on their own, the greatest advantage of modular systems is their structural reconfigurability. Modules can be combined and assembled to form configurations for specific tasks and then reassembled to suit other tasks.

In long-term space missions, for instance, a robotic system capable of adapting to dynamic situations may greatly enhance the chances of mission success. Furthermore, space missions are typically highly mass and volume constrained. Thus, sending a flexible, adaptable robotic system which can perform many types of tasks is more advantageous than sending several task-specific robots.



An iMobot module has four degrees of freedom. It can stand on its own, for instance, and if it was equipped with a camera, could scan its environment.

IMAGES: INTEGRATION ENGINEERING LABORATORY, UNIVERSITY OF CALIFORNIA

Modular robotic systems are also very well suited for dynamic and unpredictable application areas such as search and rescue operations. Modular robots can be reconfigured to suit various situations. For instance a snake-like robot can fit through tight crevices, while a larger walking robot is able to easily navigate over debris.

Quite a number of modular robotic system prototypes have been developed and studied in the past, each containing unique geometries and capabilities. In some systems a module only has one degree of freedom. In order to exhibit practical functionality, multiple interconnected modules are required. Other modular robotic systems use more complicated modules with two or three degrees of freedom. However, in most of these systems, a single module is incapable of certain fundamental locomotive behaviors, such as turning.

There remain many challenges at virtually all levels of design and control to be addressed toward the goal of an adaptive and reconfigurable modular robotic system. At the hardware level limits on joint torque and manufacturing precision will affect the performance of large modular clusters executing small, precise motions. Geometric and kinematic designs must balance strength and flexibility with module weight and longevity.

Computer software and algorithms for representing and controlling modular robots also face many challenges. Because a modular robotic system may have many degrees of freedom, algorithms for robotic clusters tend to be computationally intensive. The high computational requirements for motion planning and coordination of large clusters necessitate distributed control methods for the modular clusters. However, much work remains to be done towards distributed controllers that produce large-scale, coherent gaits.

The research group in the Integration Engineering Laboratory at the University of California, Davis conducts multidisciplinary research on robotics and information technology at the integrated system level. The group is especially interested in studying the fundamental issues of adaptive and reconfigurable systems. With this in mind, the group has developed iMobot—an intelligent modular robot, as a research and commercial platform. The group addressed a number of challenges in developing an adaptive and reconfigurable modular robotic system.

## MECHANICAL DESIGN OF IMOBOT

Similar to LEGO, iMobot is designed as a building block. However, unlike LEGO or other previously studied modular robots, a single iMobot module is a fully functional robot.

Each iMobot module has four controllable degrees of freedom. The four degrees of freedom allow a single iMobot module to perform a multitude of different locomotive gaits, including inch-worming, rolling on its faceplates, arched rolling for increased ground clearance, turning, and rolling with a minimal profile. The four degrees of freedom also allow a single module to stand up on its own without outside assistance. This self-lifting capability will be useful for modules equipped with vision sensors to inspect the robot's environment since the robot can pan around in any direction as a camera platform.

Multiple iMobot modules can be interconnected into various structural geometries for a wide variety of applications. The availability of the six exterior mount points allows the iMobot modules to be connected together in a wide variety of different configurations. The high reconfigurability of the system allows a team of iMobot modules to be effective in various types of dynamic applications simply by reconfiguring their structure. A four-legged walker, for example, is useful for rolling or walking over debris. The four-legged walker can orient its feet so that the rotating faceplates act as wheels for quickly covering open ground, or rotate at the hip to walk over rough terrain. The walker can be reassembled into a long snake-type robot, which is useful in tight quarters or as a robotic arm.

Controlling modular robots presents many unique challenges. The distributed and highly reconfigurable nature of modular robots sets them apart from task-specific robots and greatly increases computational difficulty.

In order to handle the computational complexities of large modular systems and development of distributed control algorithms, the iMobot contains a powerful, on-board miniature computing platform. The tiny computer, with a 700 MHz CPU, is capable of running a full Linux desktop environment and operates independently from the on-board motor controllers.

The computational power allows an iMobot to perform many high-level functions, such as image processing or other computationally intensive analysis. It is also capable of communicating with the on-board motor controller, attached sensors, and other modules via a high-speed communication bus. The computational collective of a cluster of modular robots can also emulate a cluster computing platform in order to rapidly execute computationally intensive tasks such as genetic algorithm-based gait generation. The desktop environment and high-speed Wi-Fi and Bluetooth capabilities of the module allow users to remotely connect to the module to execute programs, inspect data, and teleoperate the robot.

A unified software framework has been developed for programming and controlling multiple, distributed modular robots. The framework provides a simple, efficient, and fast mechanism to quickly reprogram and maintain software across a large number of robots. This allows efficient implementation and testing of modern gait generation and control techniques. To facilitate the control of iMobot modules, the software framework comprises three separate components: a C-based application programming interface, Ch (a C/C++ interpreter), and Mobile-C (a mobile agent platform supporting C/C++ software mobile agents).

**One of iMobot's modes of locomotion is an inch-worming crawl demonstrated in this photo sequence.**

IMAGES: INTEGRATION ENGINEERING LABORATORY, UNIVERSITY OF CALIFORNIA

## COMMERCIAL DEVELOPMENT

The iMobot is currently under commercial development by Barobo Inc., founded by Harry H. Cheng and Graham Ryland. Barobo has an exclusive license for the iMobot technology patented by the University of California.

Barobo was awarded an NSF Small Business Innovation Research Phase I grant to scale up iMobot for commercial deployment. With the successful Phase I completion of the NSF grant, the commercial prototype of iMobot has been developed. The iMobot has a fully enclosed design, high joint torque, and a cluster-wide communication bus, among other features.

As the first commercially available modular robotic system, its open architecture and robust programming interface will allow academic and commercial groups to perform high-level research on modular robotics. The iMobot is suited for research and teaching because of its flexible hardware, software, and electrical interface. By exposing and simplifying many aspects of the robotic design and programming, the

## TO LEARN MORE

More information about iMobot, including videos of the prototype in simulation and experimental work, is available at Barobo Inc.'s Web site, http://www.barobo.com.

The Integration Engineering Laboratory at the University of California, Davis maintains a Web site at http://iel.ucdavis.edu.

Information on Ch, the C/C++ interpreter, is available at the SoftIntegration Inc. Web site, www.softintegration.com.

Mobile C, the mobile agent platform, has a Web site at www.mobilec.org.

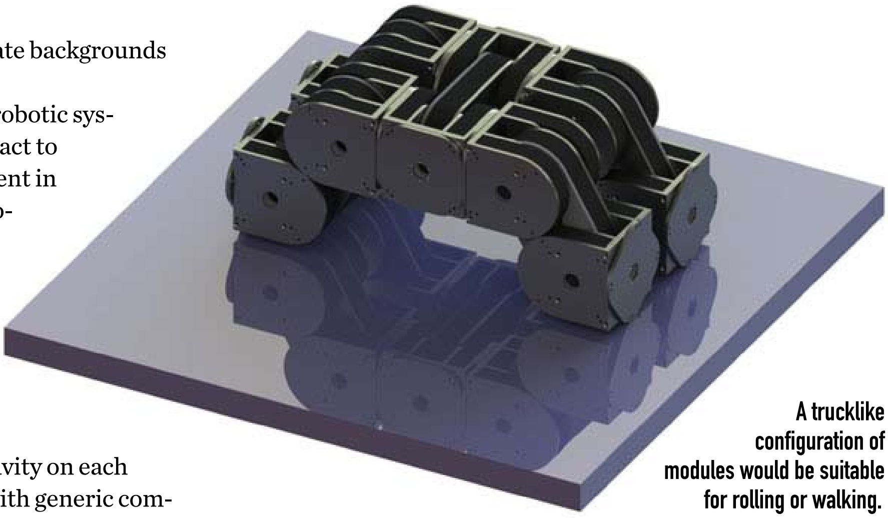
iMobot will enable researchers from disparate backgrounds to perform research on modular robotics.

Sensing is a fundamental necessity for all robotic systems. Without sensor data, robots cannot react to the dynamic events of a changing environment in which they are designed to operate. The iMobot is available with a variety of different sensors, connectors, and development kits available from Barobo.

The system is extensible, allowing users to integrate their own sensor hardware and software. Each iMobot module features six mount points; one on each of the four side plates and a recessed cavity on each faceplate. The mount points are equipped with generic communication capability allowing "plug-and-play" support for various sensors, such as IR range finders, thermal sensors, ultrasonic range finders, accelerometers, and touch sensors, as well as custom-designed sensors. The mount points are also used for communication between connected modules.

The sensors allow iMobot to better interact with its environment. For example, short-range IR sensors attached to the mount points allow users to implement obstacle avoidance algorithms for the iMobot. Articulable attachments, such as a gripper, can also be connected and controlled through the mount points.

For commercial applications, the iMobot provides an adaptable mechanical system for quickly prototyping robotic systems. The iMobot may also be used for automation, military operations, search and rescue, law enforcement, and other applications.



**A trucklike configuration of modules would be suitable for rolling or walking.**

A Starter Kit, with five iMobot modules and a suite of accessories, costs $14,950. People interested in individual module and components can contact Barobo for more information.

iMobot is the first commercially deployed reconfigurable intelligent modular robot. The research and applications of reconfigurable intelligent modular robots are still at its infancy stage. There are many challenging issues related to the control, programming, communication, and coordination of systems built with multiple modular robots. We are continuing our research to make modular robots such as iMobot suitable for various applications. ■

***Acknowledgment***

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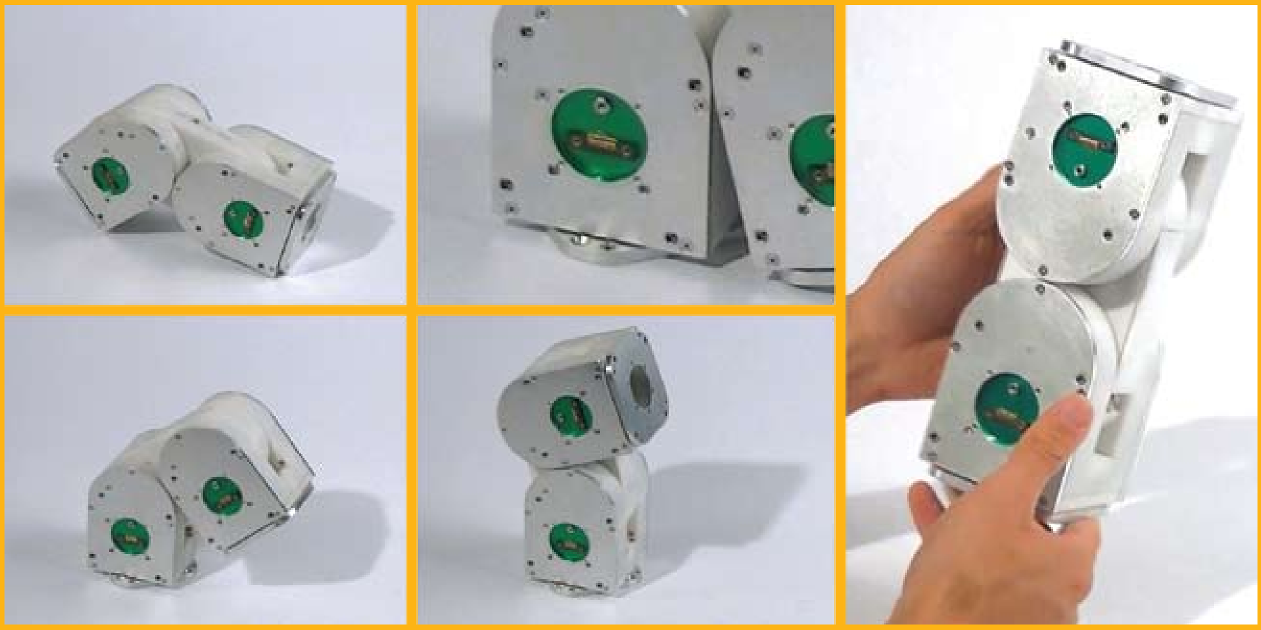

BAROBO INC.

**Commercial versions of the iMobot module. Each contains a Linux computer with a 700 MHz CPU, as well as motors and controllers.**