Time for a

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Robots have been helping manufacturers increase productivity for years, but the technology may have hit a wall unless it can become more responsive to industry's rapidly changing needs.

he night before this year's Super Bowl, another "sporting event" was being televised to a national audience across the country. Unlike their football counterparts, however, the "athletes" in this contest did not have to worry about sprained necks or pulled hamstrings, nor did they have to be concerned with contracts or endorsement deals. For the participants in the Battlebots World Championship, shown on pay-per-view around the country for $14.95 a pop, were in fact robots, dueling in a Las Vegas arena in a sporting event that was part demolition derby, part pro-wrestling, and part gladiator fight-to-the-death match.

Only in this case, "death" was temporary. Using hammers, axes, spikes, and buzz saws, the remote-controlled robots sought to put each other out of action until there was a lone survivor. But unlike the gladiators of ancient Rome, the vanquished could be rebuilt and retooled, and live to fight another day. "The competitors never have an off night," says Trey Reski, cofounder of the Battlebots series. "They don't offer excuses. They simply put it on the line all the time. And, of course, almost anything goes, so the fans always get their money's worth."

The premise that humans some day would be sitting around cheering android warriors has been confined to science fiction for more than half a century. And scientists and futurists have been predicting for many decades that robots—in the home, in the workplace, in the hospital—would have made a real impact on human life by the turn of the

By Dan McGraw

century. Unfortunately [illegible] ence needed to have [illegible] ing each other with buzz saws has been easier to develop than creating a reliable and cheap robot that can perform a variety of tasks on the factory floor.

The task of developing true artificial intelligence in a machine is much more daunting than any scientist would have thought 30 years ago. Solving the problems that seem simple in nature has been harder than the problems that were perceived as more difficult. Program[illegible] machines to do complex mathematics and play chess has proved to be incredibly easy, while programming a robot to walk—which every child learns to do—has proved incredibly difficult. Since 1986, engineers at Honda have been working on their Humanoid Robot, a machine that looks like a space explorer that is being programmed to execute a number of simple human tasks. Yet only recently have they succeeded in getting their robot to walk and climb stairs—and even these basic motor skill functions are still extremely unreliable.

"In the first flush of enthusiasm at the invention of computers, it was believed that we now finally had the tools with which to crack the problems of the mind, and within years we would see a new race of intelligent machines," writes Mark Humphreys, a researcher who studies artificial intelligence at the University of Edinburgh. "We are older and wiser now. The first rush of enthusiasm is gone, the computers that im-

Unless otherwise noted, images are from the upcoming photography book *Robo sapiens* by Peter Menzel and Faith D'Aluisio. Material World Books; M.I.T. Press; fall, 2000.

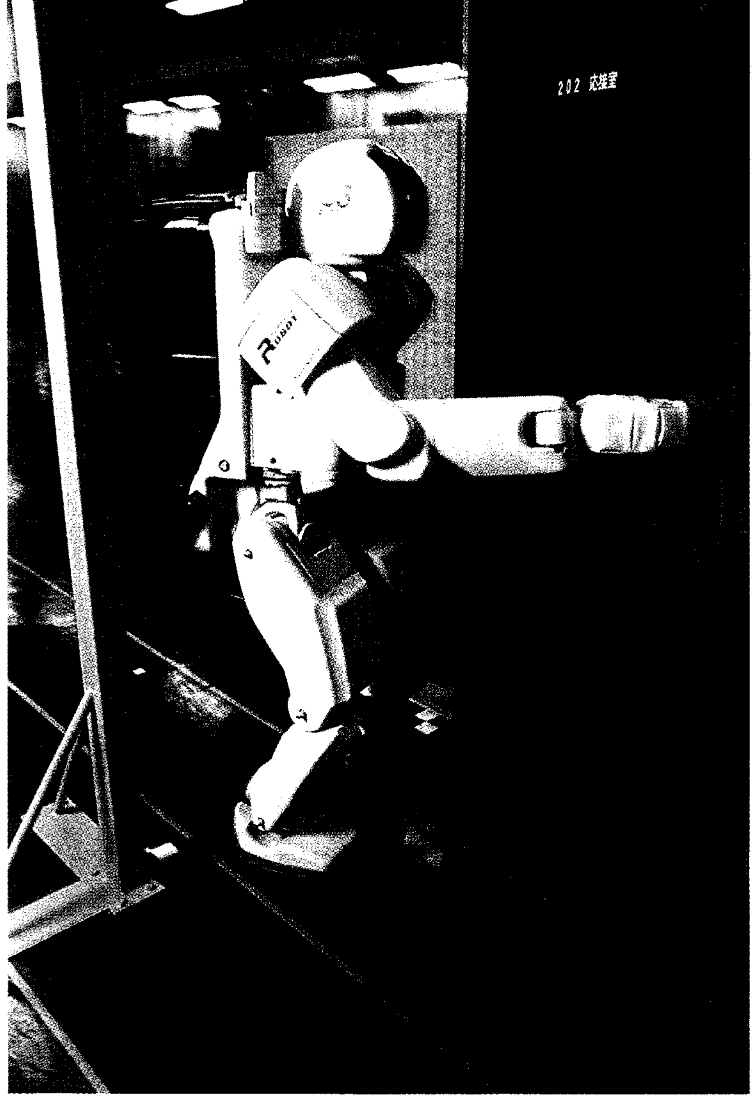
pressed us so much back then do not impress us now, and we are soberly settling down to understand how hard the problems of artificial intelligence really are."

Looking Ahead

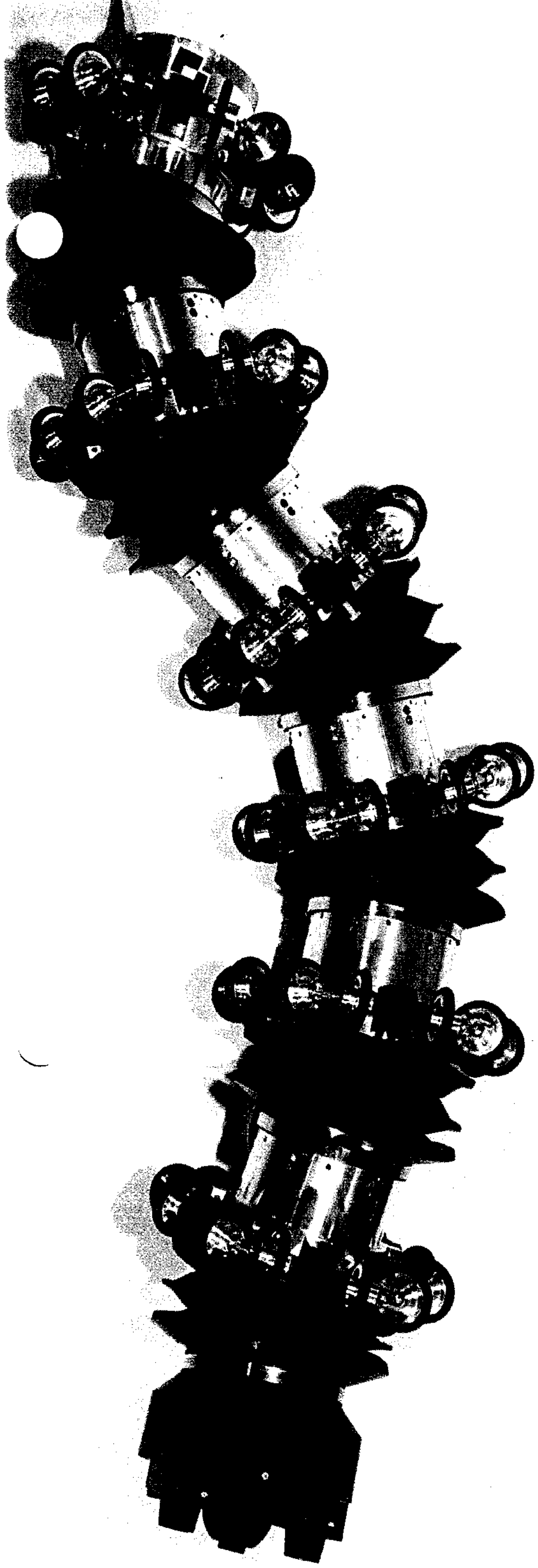
The problems of developing a new generation of machines that will remove the boring and difficult tasks from the home and the workplace are as varied and difficult as the problem-solving we are asking these machines to do. But part of the problem—especially in the manufacturing sector—is that there has been a disconnect between theoretical science and the practical applications of making products quicker and cheaper. Many scientists believe we have hit a wall with regard to innovation in manufacturing—a wall that could be torn down through better investments in more flexible machines, and through the reliance on software rather than hardware to achieve the stated goals.

In short, the computers running automated machines on the factory floor are outdated and inflexible in their approach to manufacturing. For many years, robots in industry have meant machines placed on an assembly line to perform a single task, such as the spot welders in an automobile plant. But most of these machines have relied upon built-in operating systems to run them, technology that is in some cases decades old. "The computers that have been attached to run the hardware have been terrible," says David Bourne, principal scientist at The Robotics Institute at Carnegie Mellon University in Pittsburgh. "We are dealing with thirty-year-old technology that is running these machines. You can make intelligent software, but if the machines aren't flexible, then it's like programming a rock."

The flexibility issue is now in the forefront of manufacturing, thanks to changes in the way automation has to interact with the changing marketplace. The old assembly-line model of mass production, in which identical products are churned out, is being replaced by a built-to-order, "mass customization" model. Ford Motor Co. is now studying a build-to-order model for its auto manufacturing, following the lead of companies like Dell Computer, which doesn't build a PC until it has an order for one in hand. This switch means that manufacturing companies must be able to tear



Photograph courtesy of the German National Research Center for Information Technology Institute for Autonomous Intelligent Systems.



(above, left) Honda's 5-foot-tall P-3 robot flexes its "knees" before taking a step, giving it a smoother, more natural gait.

(below, left) MIT's "Cog," shown with roboticist Rod Brooks, can play with a Slinky by mimicking a human's motions. The robot autonomously makes small adjustments to account for the toy's unpredictable motion.

(above) The German National Research Center's snake robot uses coordinated movement of multiple joints to perform inspections and other operations in hard-to-reach areas.

down and reconfigure their factory floors quickly as orders change, and the old dynamic of having an expensive robotic system that does but one task is quickly becoming obsolete.

Multiple Tasks

Compounding the problem is the compression of the life cycle for many high-tech products. If a product has a life cycle of nine months, and the ramp-up time to install an automated system that will manufacture that product is six months, the point of automation is moot. But the question that remains for most robotics manufacturers and engineers studying the problem is whether robotics systems can become flexible, do-it-all machines.

The dicey solution to this problem lies in the history of the development of robotics technology. The word "robot" first appeared in 1921, when Czech writer Karel Capek wrote a play about humanoid machines that would relieve the world from the tasks of drudgery. The robots (from the Czech word for forced labor or serf) in the play initially bring great benefits to humans, but in the end bring an equal amount of blight in the form of unemployment and social unrest.

In 1958, Joseph F. Engelberger, an engineer, and George C. Devol, an entrepreneur, invented a robot named "Unimate," a machine that General Motors would eventually use to work with heated die-casting machines. Over the years, however, the robotics research community split into two camps. Entrepreneurs like Engelberger and Devol designed machines that would perform specific tasks—such as spot welding, painting, and material handling. The theorists, on the other hand, worked on the more difficult problems of replicating human behavior, developing sensors to mimic vision, touch, and voice. They wanted to design machines that would, in some basic way, think.

The captains of industry, predictably, had little use for the theoreticians; they wanted reliable machines that would perform automated tasks to save on labor. Thus with assembly lines running and stamping out product after product in the mass production system, there was little incentive to innovate.

In recent years, however, industry's needs have changed and the robotics field has sought to keep pace. According to Purdue University industrial engineering professor Shimon Nof, author of the *Handbook of Industrial Robotics* (John Wiley & Sons, 1999), the world robot population has surged in the past two decades, rising from 35,000 in 1982 to an estimated 950,000 in 2000. From 1992 through 1997, the robot population in North America has grown 78 percent, from 46,000 to 82,000. The ratio of robots to manufacturing jobs has also increased: from 1980 to 1996, the number of robots per 10,000 manufacturing jobs increased from 8.3 to 265 in Japan; in Germany, from 2 to 79; in Singapore, from 0 to 98, and in the Unites States from 3 to 38.

According to the Robotics Industry Association, in the nine months ending in September 1999, a total of 13,369 robots worth $1.1 billion had been ordered from North American robotics manufacturing firms, up 62 percent in units and 40 percent in dollar value from the previous year. And despite the growth, the market is still wide open; the RIA estimates that only 10 percent of the manufacturing companies that could benefit from robots have installed them.

Indeed, robotics may be one of the factors contributing to the higher levels of productivity in the manufacturing sector of the economy. During the fourth quarter of 1999, productivity rose at a five percent rate, the strongest showing since 1992. Overall worker productivity in 1999 rose 2.9 percent, the largest spurt of growth since a 4.1 percent gain in 1992. All of this has been achieved with national unemployment levels hovering around the 4 percent level.

"The fear that robots would replace workers has completely disappeared," says Nof. "We have so many people trained in robotics now. Some new challenges for robotics researchers are better human-robot collaboration interfaces, robot mobility and navigation in unknown surroundings, and better robot intelligence for services and for public transportation."

Software Solutions

Much of the improvement in these systems involve software innovations rather than hardware. Many companies are moving toward cell manufacturing systems, an old idea that is catching fire as a way to deal with flexible manufacturing systems. Cell manufacturing relies on multiple manufacturing groups rather than one long assembly line.

In the era before the industrial revolution, groups of people would make products in their homes by passing the product from one person to the next. One person might carve a piece of wood, the next might install a handle, the third might put a blade on the piece, the fourth might paint it. The end result would be an ax. If the market in the village for axes was small, they would switch to making buckets. The same theory is being used today to manufacture different products. At Compaq Computer in Houston, groups of four factory workers assemble machines based on orders. When the orders change, their jobs change, and all are trained to do multiple tasks.

Getting robots to be flexible like this is a challenge. Modules of hardware components need to be developed so their parts can be reassembled quickly to perform different tasks, and the software systems can be programmed from a central location to integrate the hardware. The robotics industry is trying to catch up with the new dynamics. "

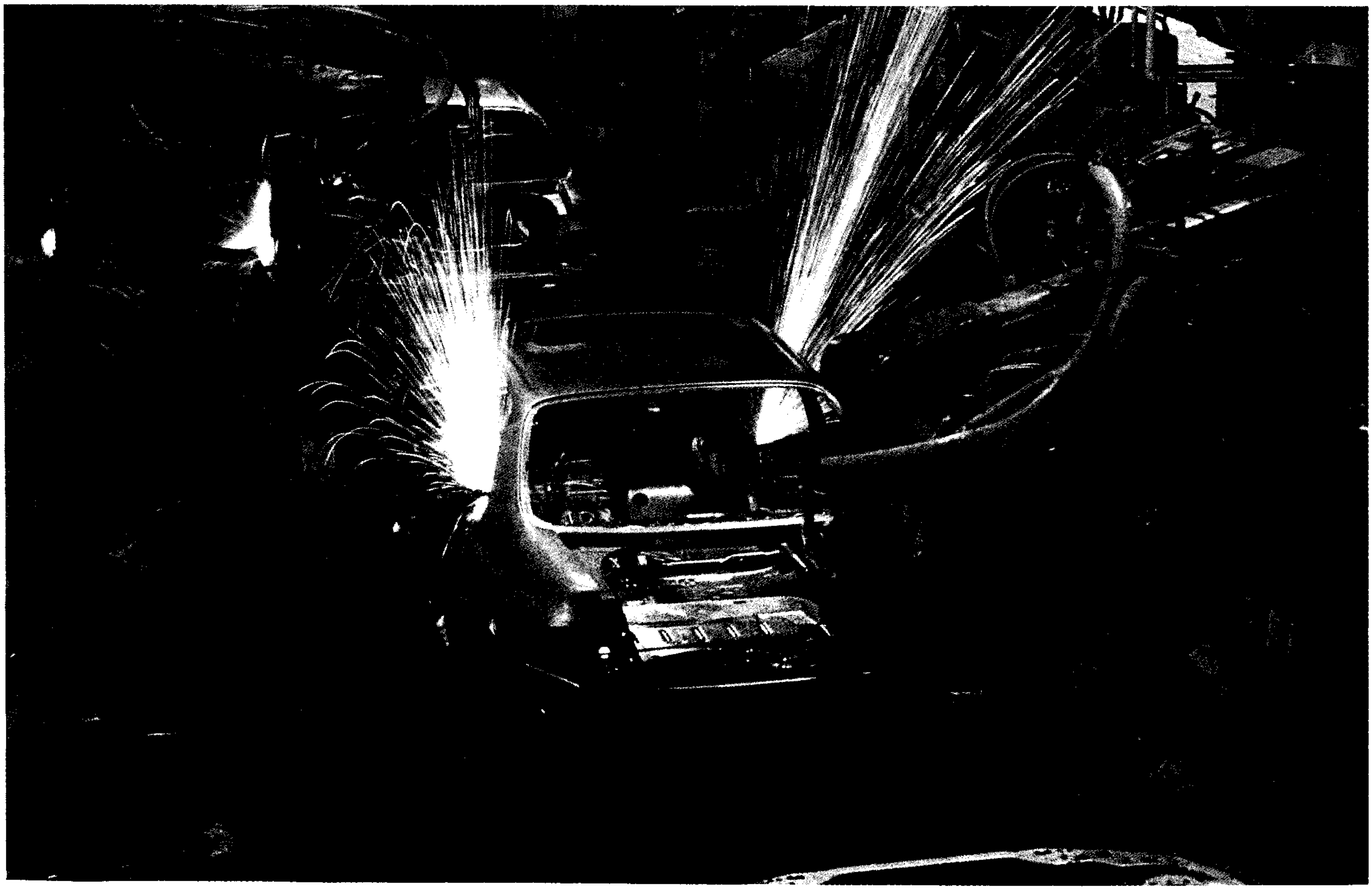
Robots are not the issue," Brian Carlisle, chairman and CEO of Adept Technologies in San Jose, a leader in flexible robotics technologies, said in a recent interview. "System integration is." Brian Demoe, marketing manager for Trellis Software and Controls in Rochester Hills, Mich., estimates that the role of software relative to hardware has increased over the past five years from a fifty-fifty ratio to an eighty-twenty ratio. "Software is the glue that holds it together, from the controller to parts to factory to enterprise," he says.

But the bottleneck to create a flexible system occurs at the robotics manufacturers themselves. Flexible systems, relying on software that can run a host of different machines, means that manufacturers no longer will have a lock on proprietary systems. Many companies would be able to sell software and sell components that would fit into larger systems. "They have hit the wall," says Delbert Tesar, director of the Robotics Research Group at the University of Texas at Austin. "The technology is closed and proprietary. With universal software, these machines could run a variety of tasks and be cheaper to implement. The industry has to realize that the future is ahead of them, and not behind them.

"And a problem that engineers have in designing these flexible systems is that they not only have to be able to be programmed quickly, they need to be maintained by a person who has a basic high school education," Tesar says. "But it's been done in other high-tech fields, so why not in robotics?"

Medical Model

The robotics manufacturing industry might well look to medical technological breakthroughs as a model for flexibility. Engineers at the University of Pennsylvania are developing a wheelchair that navigates stairs and rough



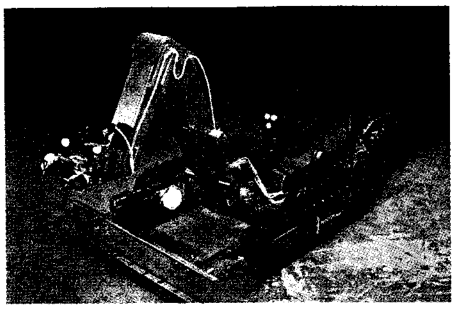
Photograph by Andy Sacks

(above) Single-function stationary robots, such as automated spot-welding machines in automobile plants, have long been the dominant form of industrial robotics. But as "mass customization" catches on, companies may need more flexible, software-driven systems to continue making productivity gains.

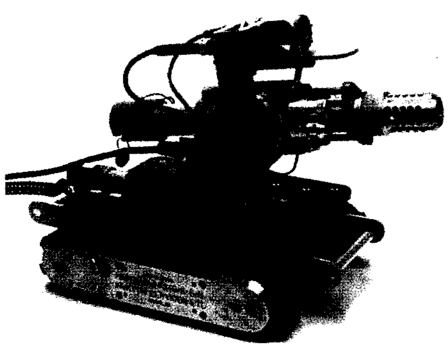
surfaces. Sensors on the chair can detect changes in the terrain, and an on-board computer can be used to program new directives immediately.

Researchers at Carnegie Mellon University are developing a robot named Flo, designed primarily for elderly patients. Flo reminds patients to take their medicine, opens prescription bottles, collects data like vital signs and transmits it directly to physicians, and allows patients to interact directly with their physicians through a monitor/camera interface. More important, Flo can be programmed to do specific tasks based on the patient's needs.

Robotic surgery is now being tested



Photograph by Matt Bulvony

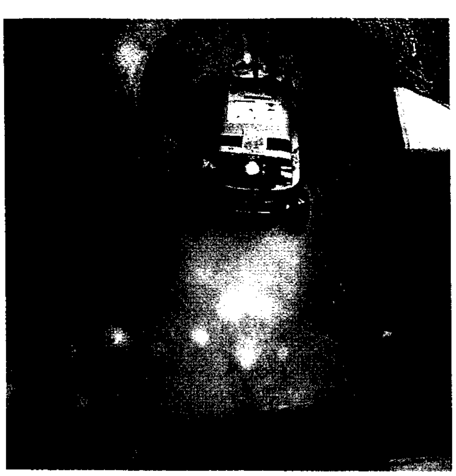


Photograph by Mark Kaarreman, Imageplay Photography

(top) "Houdini," manufactured by RedZone, can remove waste from large tanks.

(above) The Mobile Disrupter Vehicle developed by Inuktun Services Ltd. uses a waterjet cannon to disarm suspicious packages for bomb squads.

(below) The German National Research Center's sewer inspection robot, KURT, uses laser guidance to steer itself to problem areas.



By Ray Bert

Robotics professors find themselves in an amusing position. In doing their own work on artificial intelligence, they strive for the ultimate goal of teaching an entity how to think and to learn on its own, so that it can handle both routine tasks and unanticipated problems. In helping their students to become productive robotics engineers they confront . . . the exact same problem.

In courses from mechanics to electronics, complex mathematics to high-level programming, robotics demands understanding and skill and—perhaps more important—the ability to confront problems that aren't always sharply defined, and that require knowledge that the student does not yet have. "Robotics problems are very similar to what engineers encounter on the job in many industries," says Vijay Kumar, deputy dean of the school of engineering and applied science at the University of Pennsylvania. "Your chances of knowing more than 10 percent about a given subject are usually very small."

The kind of broadly defined problems that robotics attempts to address—for example: design a mobile robot that can build and repair space trusses—gives the students who learn how to tackle them a huge leg up. In such situations, the budding engineers come to appreciate the value of persistence. "In robotics, students quickly learn that nothing works the first time," says Matt Mason, chair of the Ph.D. robotics program at Carnegie Mellon University.

Of course, engineering schools offer plenty of structure to prepare students—often in the form of a laundry list of required courses in various disciplines. Still, "students really learn to do robotics in capstone-type courses," says Kumar, who is also director of Penn's General Robotics and Active Sensory Perception Laboratory. "We try to ask open-ended questions to make students think on their own and realize their limitations." Such courses, as well as labs, high-profile projects, and competitions—Penn takes part in the popular RoboCup, in which students build and program teams of soccer-playing bots—help students put together what they have learned in all the many disciplines that figure in robotics work.

The multifaceted experience that students gain is a blessing in another way, as well; because the actual robotics industry is small, many graduates will need—or want—to seek jobs elsewhere. And their options are wider than you might imagine.

"What people don't see is that between a single-function robot and one that tries to emulate a human being, there are many possibilities," Mason says, noting that speech recognition technology, many types of sensors—even the data mining software so popular in marketing circles—all are related closely to robotics work. Kumar concurs, and adds such "fun jobs" as working on aircraft simulators or animatronic amusement park figures to that list.

Kumar and Mason both note that robotics education has changed somewhat as new applications have proliferated, bringing with them niche areas of specialization. Mason cites the sheer number of courses available as a prime indicator of that phenomenon. But while the educational side is trying to keep up with the times, Kumar feels that industry has some catching up to do, as well.

"Things that you see in industry today are more automated than autonomous—very structured, mostly articulated arms," he says. "In my mind, this is driven by economics." Kumar believes that more flexible, autonomous robots will become prevalent in industry only when more money is devoted to the cause.

"What we teach allows students to think about robots that will be able to mimic humans," he says. "We cover decision-making, autonomy, control—so that our students will be equipped to design the next generation of robots."

Ray Bert is senior editor of Prism.

by the Food and Drug Administration in a 60-patient clinical trial. The surgeon manually manipulates two instrument handles that send a digitized message to the instrument handles in the operating room. The result in heart bypass surgery has been tiny incisions—about the width of a pencil—instead of the large incision and chest "cracking" that is needed for traditional open heart surgery. The patient's heart continues to beat during the entire procedure, and recovery time is reduced by weeks. Plus, robotic surgery could be done from from remote locations, enabling a talented surgeon to perform surgery on a patient a continent away. "It's going to have a major impact not just on cardiac surgery, but on all kinds of surgery," says Ralph Demiano, Jr., chief of cardiothoracic and vascular surgery at Hershey Medical Center.

If history says anything about the development and future of robotics, it is that scientific breakthroughs come quicker when the research is geared toward problem solving and human need, rather than theoretical stabs at recreating human artificial intelligence. That's why Sony's robot pet, Lego's programmable robot toy, and the popularity of the Battlebots have gained great favor in the marketplace. But it is somewhat disconcerting that the computing ability on these toys is in many measures greater than the computing ability of machines on factory floors. The challenge for mechanical engineers and computer science professionals is to integrate the two disciplines more completely, to increase productivity and develop a more cost-effective way to assist workers and make products.

"People talk about productivity increasing by five percent and they think that is great," says Carnegie Mellon's Bourne. "But that is just the tip of the iceberg as far as productivity goes. There has been a gaping hole in the development of industrial robotics since 1985. The technology is there now to create the systems that industry needs. As soon as the machine tool companies realize that an open architecture system, flexible to the needs of manufacturers, is good for them—only then can we realize the real potential of robotics."

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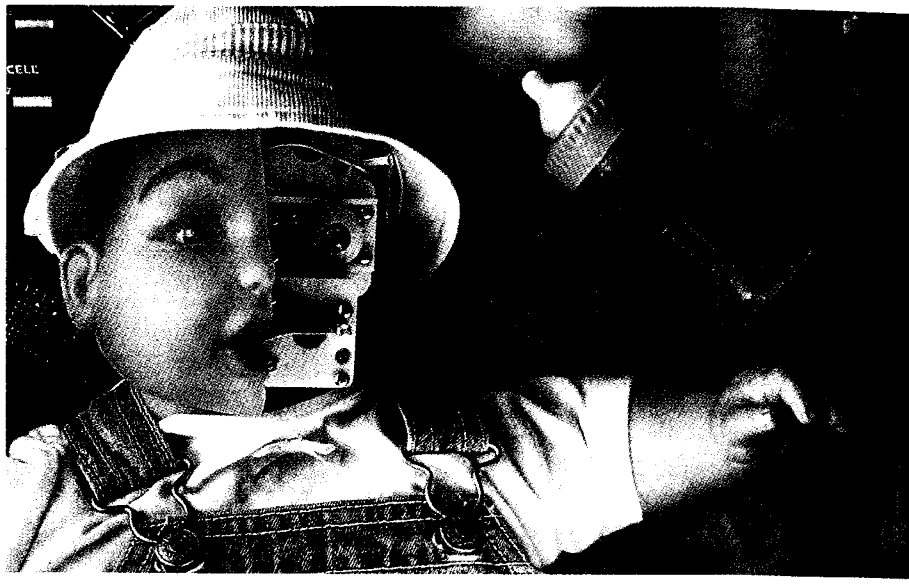

(above) A doll with mechanical inner workings that alter its facial expression may make its debut at Christmas.

(right) A robotic hand developed by the German Aerospace Agency uses "force feedback" to carefully control grip strength.

(below) MIT's "Kismet" can recognize and react to human expressions—here it is showing "surprise."