SUMMER• 2000

# SANDIA TECHNOLOGY

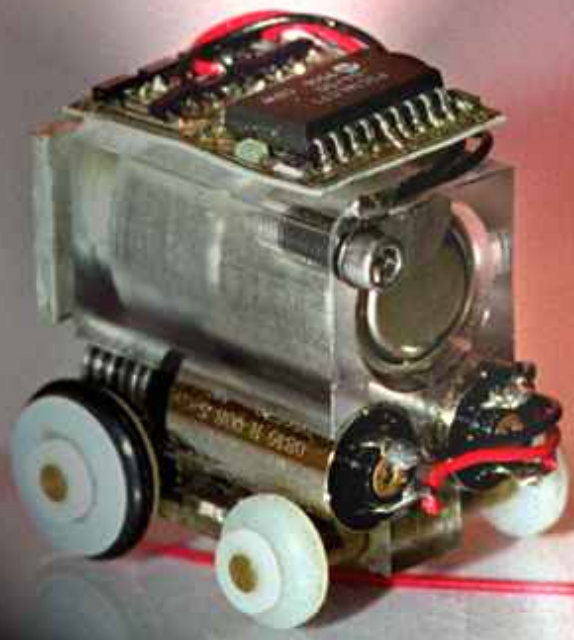
A QUARTERLY RESEARCH & DEVELOPMENT JOURNAL
VOLUME 2, NO. 2

## SMART MACHINES
### The Robotics Revolution

ALSO:

Smart Scalpel Detects Cancer Cells

Shrinking Prostate Glands Without Surgery



Sandia National Laboratories

A Department of Energy National Laboratory

Sandian Phil Bennett (right) discusses potential enhancements to a bomb squad robot with Albuquerque Police Department bomb techs Detective Wayne Cunningham (left) and Patrolman Stephen Chester. Sandia is training police officers throughout the United States in how to use robotics in advanced bomb-disposal techniques.

*ON THE COVER:* MARV (Miniature Autonomous Robotic Vehicle) is one of the world's smallest autonomous vehicles, containing all necessary power, sensors, computers, and controls on board. MARV is a three-year-old technology measuring one cubic inch in size.

*(Photo by Randy Montoya)*

*Sandia Technology* is a quarterly journal published by Sandia National Laboratories. Sandia is a multiprogram engineering and science laboratory operated by Sandia Corporation, a Lockheed Martin company, for the Department of Energy. With main facilities in Albuquerque, New Mexico, and Livermore, California, Sandia has broad-based research and development responsibilities for nuclear weapons, arms control, energy, the environment, economic competitiveness, and other areas of importance to the needs of the nation. The Laboratories' principal mission is to support national defense policies, by ensuring that the nuclear weapon stockpile meets the highest standards of safety, reliability, security, use control, and military performance. For more information on Sandia, see our Web site at *http://www.sandia.gov.*

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# FROM THE *Editor*

Dear Readers:

Sandia National Laboratories has developed one of the strongest and most diverse robotics and intelligent systems programs in the world. The reason is clear: As the nation's primary nuclear weapons engineering laboratory, Sandia regularly works with hazardous materials and in dangerous environments. And work on nuclear weapons and related activities must be done with precision and is often highly repetitive. Robotics—particularly intelligent systems that integrate computers, sensors, and mechanical components—provide the ideal tool to accomplish precision work in hazardous environments.

Sandia also provides an ideal climate to conduct robotics and intelligent systems research. Among the labs' approximately 7,300 employees are many of this nation's brightest physicists, computer scientists, chemists, aerospace and aerodynamics scientists, and engineers—mechanical, civil, nuclear, and electrical. More than 120 of these diversely talented individuals work in the labs' 73,000-square-foot Intelligent Systems and Robotics Center and at the 226-acre Robotic Vehicle Range.

While Sandia's robots and intelligent systems were designed for specific mission-related work, many of them have applications ranging from the manufacturing floor, to the operating room, to the battlefield. Sandians have helped design systems for building cars, working in outer space, handling food, and even one that provides a better way to sew blue jeans.

As society's needs expand and the technology improves, it may not be that long before we begin to see robotics become a part of our daily lives, in areas as varied as housecleaning, cooking, field labor, to even smart cars that avoid collisions.

Chris Miller

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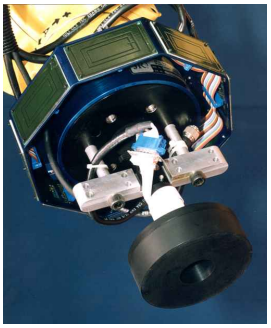





## INSIGHTS

***by Patrick J. Eicker, Director, Intelligent Systems and Robotics Center, Sandia National Laboratories***

# *Thoughtful Acts*

# Smart Machines

"We expect a robotics revolution by the year 2020," says Pat Eicker, director of the Intelligent Systems and Robotics Center at Sandia.

"Intelligent machines technology is poised right now to offer national defense and commercial applications so profound they will fundamentally transform many aspects of our everyday lives."

# Tight budgets, concern for worker safety, the push for increased productivity, and a need for precision quality—Sandia National Laboratories has responded to these national needs and concerns by developing robotics and intelligent machines (RIMs).

In 1998, the U.S. Senate and House Task Forces on Manufacturing asked the Department of Energy, the Department of Defense, the National Science Foundation, NASA, and the Department of Commerce to develop a technology plan, called a *roadmap*, to identify fundamental research needs for the near (five years) and long (20 years) terms.

The DOE roadmap noted four cross-cutting themes: cost reduction, worker safety, product quality, and increased productivity. In addition, these technology areas were identified where RIMs will revolutionize DOE operations: manufacturing, hazardous and remote operations, and monitoring and surveillance.

The roadmap already has spawned new technologies that are benefiting industry and academia. The technologies are helping to lower production costs, in part because RIM technology is reducing human involvement and human error. Worker health and safety are on the rise because more people are being removed from radioactive and other hazardous environments. Product quality is improving because of decreases in design and production-related defects. And productivity is on the upswing because remote systems are operating faster than those of the past.

RIMs conduct tasks as varied as packaging, painting, chemical and physical characterization, cleaning, assembly, disassembly, soldering, explosive powder dispensing, deburring, and edge finishing.

DOE offices that contributed to the Robotics and Intelligent Machines Roadmap were Defense Programs, Fissile Materials Disposition, Environmental Management, Nuclear Energy Science and Technology, Science, Nonproliferation and National Security, Environment Safety and Health, Energy Efficiency and Renewable Energy, and Fossil Energy.

Microrobotics hold promise in the manufacture of micromachines or for assisting in microsurgery, manipulating human red blood cells, detecting minefield explosives, and conducting search and rescue after a disaster. The benefits and beneficiaries of robotics research increase every year. But in many cases, the source remains the same—national security research.

## THE FUTURE HAPPENS HERE

Sandia robotics technologies have developed out of 50 years of research supporting nuclear-weapons surety and national security. Today research must adapt to new threats—threats that include terrorist and chemical or biological attacks on battlefields and in urban areas. Military operations are constantly undergoing changes to meet the needs and demands of modern warfare. Sandia is developing robotic systems to operate in a variety of terrain, from the desert, jungle, swamp, mountains, forest, and arctic, to urban settings. These intelligent systems combine sensors, software, modeling-and-simulation, and electromechanical devices that enable researchers to create machines that perceive, reason, navigate, and manipulate.

These robots can perform reconnaissance, surveillance, integrated analysis, target acquisition and object recognition, damage assessment, and distinction of friend from foe. In performing their work, they can communicate with each other and with remote operators via satellite.

Future battlefields will have fewer soldiers and far fewer casualties. For instance, a robot could be programmed to recognize a tank and disable it without ever putting soldiers at risk.

"Current combat systems are heavy and large and create a big logistics challenge," said Dan Rondeau, manager of Development in Sandia's DoD Programs Division. "Those systems are large to protect the people inside. Future combat systems will be much lighter and will require fewer soldiers to operate them."

# The Hub of Robotics Activity,

# Intelligent Systems & Robotics Center


Sandia National Laboratories' Intelligent Systems and Robotics Center (ISRC) develops technologies to perform a vast array of tasks, from defense manufacturing and materials handling to environmental remediation and battlefield applications. The center designs mobile robotic systems to carry out tasks that are too difficult or dangerous for people. Sandia develops the "brains," or software for robotic systems; creates the "eyes," or sensors; and integrates hardware, software, and mechanical components, including micromachines, to create robotic systems.

The ISRC's more than 120 scientists and engineers design and develop robots for national security and nuclear weapons stewardship. The center consists of a 73,000-square-foot research facility and a 226-acre robotics test range.

Sandia's mobile robotics program began in 1984 and has led to the development of more than 40 systems for surveillance and reconnaissance, accident response, environmental sensing, weapon delivery, security monitoring and testing, and hazardous material handling.

*The ISRC's more than 120 scientists and engineers design and develop robots for national security and nuclear weapons stewardship. The center consists of a 73,000-square-foot research facility and a 226-acre Robotic Vehicle Range.*

The center specializes in developing automated systems to produce small numbers of high-value components at reasonable cost, said Pablo Garcia, manager of Applied Systems. The center works to reduce the costs of software and tooling while producing quality that is consistent and repeatable, he said.

The center's robotics have applications in such diverse areas as microsurgery, toxic-waste cleanup, and manufacturing. Industries that use Sandia-developed robotics technologies include apparel, material handling, food preparation, health care, and construction. Sandia transfers robotic technology to the private sector through cooperative research and development agreements (CRADA's).

*Cost-effective flexibility*

# ISRC TECHNOLOGIES MEET THE CHALLENGE

A robot is a machine programmed to work. A computer-control system typically guides the robot. Sensors enable it to recognize objects, or to carry out such tasks as detecting chemical and biological agents.

A major challenge for Sandia's Intelligent Systems and Robotics Center (ISRC) has been the development of robots and intelligent machines (RIMs) that have the flexibility to perform multiple tasks, and still be produced in small numbers at a reasonable cost. The robots must respond to a variety of customer needs in such diverse areas as environmental restoration, surgery, manufacturing, and military operations. In response, the ISRC has developed a variety of static and mobile sensor-driven robots, as well as teams of cooperative robotic systems that have computerized vision, dexterity, and the ability to recognize and move around obstacles.

## THE TECHNOLOGIES

***Another way to define robots or intelligent machines is to describe the way they behave. They can swarm (converge on an object), cooperate (share information and parse work to achieve an objective), or act autonomously. Robots also can interact with humans, who share in command-and-control activities, or humans may control the robots entirely through teleoperation. Robots also are being designed to learn and perform new tasks. This is known as emergent behavior.***

***Sandia robotics and intelligent machines often combine many technologies. The following RIM technologies are grouped by the enabling capability.***

### Automated Planning & Programming Software

Software gives a machine intelligence. When combined with sensors, software enables machines to assemble, disassemble, paint and clean surfaces, retrieve, inspect, and perform other processes such as computer-aided design.

• Archimedes—automated assembly analysis—determines multiple ways a product can be assembled. The software follows a computer model to find part-to-part contacts, generate collision-free insertion, and select assembly order. The designer specifies a task (such as part insertion or fastening) and Archimedes considers thousands of combinations to determine the best assembly sequence and then ranks the sequences by quality metric. The designer can immediately test changes, assess for feasibility, and communicate design-for-assembly requirements. The result is faster generation of high-quality assembly sequences without the need to produce a physical prototype.

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*Archimedes is a planning-and-visualization software. It generates, ranks, verifies, and examines assembly sequences. Product and process engineers use the technology to define constraints, determine alternatives, optimize assembly according to user specifications, and communicate the results quickly and graphically.*

• Feature-recognition software investigates the computer-aided design- (CAD) to-finished-product process to find pertinent features from a solid model. Engineers are able to analyze the model in their terms without going through the laborious process of constructing application-based features from low-level geometric and topological entities. Some of the current and potential applications of the software include part coding, machinability analysis, process modeling, assembly, fixturing, and cost estimation.

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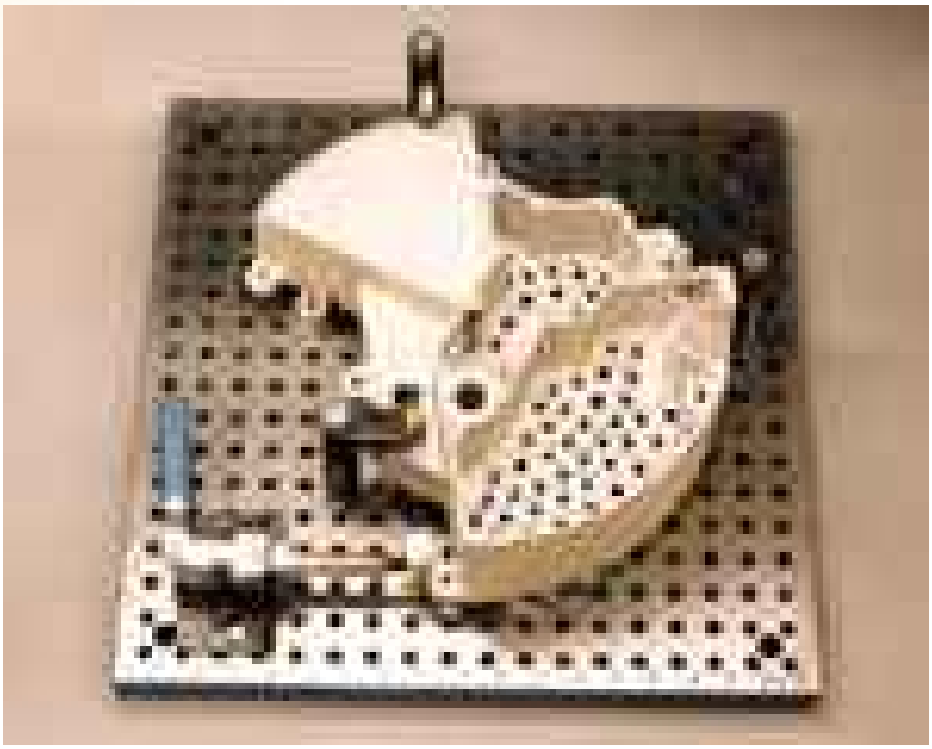

A Holdfast ©-designed pallet using locator pins and supports allows for mixed-part assembly; the glue gun and cassette mechanism can be assembled on the same pallet at different times.

• HoldFast © designs fixtures to hold objects for machining, finishing, and assembly during their manufacture. Designers provide a CAD definition of the workpiece geometry and define the workplace material. The technology greatly reduces fixture design and cost by producing multiple fixture designs that solve specific fixturing problems. It then ranks the designs using a quality metric. HoldFast© allows manufacturers to design modular fixtures for prototype or small-lot production, or pallet-type structures for large-scale production.

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## Sensors and Sensor Software

Key to many RIMs are sensors and software that convert sensor information into maps of the environment. Thus, robots are enabled to apply "reason" to locate or avoid elements in an unstructured environment.

• The capacitive tool standoff sensor for dismantlement tasks is composed of a noncontact capacitance sensor installed on the tool plate of a robotic manipulator. The technology is used to keep robots at the correct distances and orientations with respect to surfaces in hazardous environments. The standoff sensor system consists of a four-inch diameter sensor inside a rugged plastic case. It can be attached to robotically deployed tools, such as routers and grinders. The sensor system works by emitting four electric fields that detect surfaces up to six inches away. When the sensor approaches the work surface, the electric fields are disrupted, creating a capacitance change between electrodes. The changes are measured and fed back to the robot control system, which then redirects the robot. Applications include metal cutting and surface scanning and mapping.

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Sandia's standoff sensor system, which senses the presence of objects without touching them, allows automated systems to position tools in unstructured environments.

• Cloud to CAD produces CAD representations of existing parts, using range sensors to scan parts and to produce a loosely connected cloud of data points that describe the distance from a receiving camera to the object. Just as a cloud is an amorphous gathering of water droplets or ice particles, a "cloud" of data is an amorphous collection of data points. Cloud to CAD serves as a method of crystallizing this data into a coherent structure.

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• High-definition, 3-D ultrasound imaging combines robotic controls, image processing, and artificial intelligence to improve the resolution of medical diagnostic images. The system combines raw ultrasound scans to produce a 2-D slice. Slices are stacked to form a 3-D data set. The 3-D anatomical geometry can be used to fabricate custom prosthetic limbs. This technology offers cost-efficient portability and high resolution. Three-dimensional ultrasound imaging has applications in manufacturing, in antiterrorist mine and bomb imaging, and in military combat for casualty diagnosis, in addition to health-care uses.

***Ultrasound depends on angle of incidence for contrast and resolution. The images can be improved by using a patent-pending technique called high-definition, 3-D ultrasound imaging.***

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• MiniLab, a chemical lab in a box, can analyze hazardous materials on site. Various sensor systems are integrated into a flexible software and hardware framework. Because many of the sensor systems are commercially available, MiniLab can be customized for specific applications. The technology measures waste properties, such as radiation, pH, chloride concentration, galvanic currents, temperature, combustible gas, and viscosity. MiniLab also can include instrumentation and video systems for viewing and positioning.

MiniLab conducts characterization of underground chemical and radioactive waste in a faster, safer, more cost-efficient way than was previously available.

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• RATLER™—Robotic All Terrain Lunar Exploration Rover—can cooperate with other robotic sentries to protect a perimeter. The sentries investigate an area after intrusion-detection sensors set off alarms. The original RATLER™, measuring one meter across, was developed for a lunar mission. The SWARM-RATLER™, measuring 18 inches by 18 inches by 9 inches tall, is equipped with an Intel computer chip, a global-positioning-system receiver, two-way radios, an electronic compass and tilt sensors, video camera, radio-frequency (RF) video transmitter, and a suite of autonomous navigation software capabilities.

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• TMSS—Telemanaged Mobile Security Station—is a mobile robotic system designed for autonomous security patrols in hazardous or restricted areas. The system uses a Honda all-terrain vehicle with a mounted video camera that detects motion, a microwave motion sensor, a passive infrared motion sensor, and a covert near-infrared illumination spotlight.

***TMSS can support physical security in areas requiring high vigilance and mobile patrol.***

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Sandia is developing and testing a perimeter-detection system using a cooperative team of robotic sentries that investigate intrusion alarms.

## Integration Technologies

The ISRC integrates technologies, including complex electromechanical devices with sensors and software, to construct reliable, intelligent machine systems.

• Bot, a 10,000-pound robotic arm, can automatically paint the Stealth fighter jet. The system sprays a thin radar-absorbent coating onto the skin of each of the nation's active F-117 Nighthawks at a higher quality and lower cost than human workers.

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A Sandian examines a pair of cameras that provide feedback to the computer system controlling the automated paint system for the F-177 Nighthawk jet.

• Fire Ant uses an autonomous standoff mine to destroy enemy armor. A video motion detector provides target acquisition and tracking, and firing solutions. The platform is teleoperated to an observation point, is armed and the automatic target recognition (ATR) detects, tracks and fires on targets. In the initial version of Fire Ant, the robot is destroyed when it fires the explosively shaped projectile. The robots are not destroyed in new versions, using more lethal explosively formed projectiles (EFPs).

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• SARGE—Surveillance And Reconnaissance Ground Equipment—incorporates computing and sensing systems onto a Yamaha all-terrain vehicle. SARGE offers day and night imaging as well as thermal imaging and a high-power, zoom surveillance camera. SARGE is being used to develop doctrine and tactics for use of teleoperated equipment by the U.S. military.

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• SMART—Sandia's Modular Architecture for Robotics Teleoperation—is a software tool for building user-friendly telerobotic systems from commercial hardware. SMART consists of three components: an editor (to define, develop, and generate telerobotic behaviors); a supervisor (that allows the operator to quickly switch behaviors, change module settings, and display results); and a real-time engine (equipped with the algorithms, device drivers, state engines, and servo loops needed to implement telerobotic control). SMART capabilities include multi-arm telemanipulation, prescribed-motion paths, collision avoidance, and joint locking for positioning. Approximately 200 modules are available and can be rapidly exchanged to create customized systems.

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Fire Ant, an early example of a mobile autonomous armor-defeating system, uses an explosively formed projective (EFP). Sandia continues to develop more lethal warheads for integration onto mobile platforms.

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# NEWS Notes

## 'SMART SCALPEL' QUICKLY DETECTS CANCER CELLS

Scientists at Sandia National Laboratories have developed a "smart scalpel" mechanism that can detect the presence of cancer cells as a surgeon cuts away a tumor obscured by blood, muscle, and fat. The dime-sized device, called a biological microcavity laser, should help surgeons more accurately cut away malignant growths while minimizing the amount of healthy tissue removed.

In effect, the patented device would tell a surgeon when to stop cutting.

"We can quickly identify a cell population that has abnormal protein content, as do tumor cells, by passing only a few hundred cells — a billionth of a liter — through our device," said Paul Gourley, leader of the Sandia effort.

The device, more briefly referred to as a biocavity laser, has distinguished in the laboratory between cultured cells consisting of normal human-brain cells called astrocytes, and their malignant form, called glioblastomas, with excellent results. The brain is a particularly critical place to know when enough tissue has been removed.

Dr. Steve Skirboll, a member of the neurosurgery department at the University of New Mexico's School of Medicine, is helping to determine the characteristics of the biocavity laser. He said the device has great potential benefit: "We're able to flow cells in real time, which no current device I'm aware of can do."

The device works by incorporating blood cells into the lasing process, rather than shining a laser light like a spotlight upon the cell. A vertical microlaser beam enters individual cells as they are pushed by a micropump through tiny channels cut into the glass surface of the device. Because cancerous cells contain more protein than normal cells, their additional density changes (by refraction) the speed of the laser light passing through them.

A receiver registers this change as a difference in output frequency and transmits it by optical fiber to a laptop computer a few feet from the instrument. An algorithm translates the data into a graph that provides surgeons with easy-to-read peaks and valleys that clearly depict when blood pumped from the incision has been cleared of cancerous cells.

The Department of Energy has selected the work as best project of the year among its 28 U.S. labs in a competition in the Basic Energy Sciences division.

Sandia researcher Paul Gourley examines the photomask used to microfabricate the biocavity microlaser flow device.

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• Surfwedge clears a path through mine-infested waters to ensure the safe landing of personnel craft. Sandia designed and built Surfwedge in 30 days for the U.S. Marine Corps. Surfwedge can easily be installed on unmanned, sacrificial boats. A number of these sacrificial boats are driven through shallow water to detonate water mines, after which landing craft with personnel can safely follow.

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Surfwedge clears path through mine-infested waters.

## *The Intelligent Systems and Robotics Center*

# PARTNERSHIPS

The Intelligent Systems and Robotics Center (ISRC) works with a spectrum of partners—in government, industry, and academia— to conceptualize and develop the nation's leading-edge technologies. The following is just a sample of the wealth of ISRC partnerships:

• Lockheed Martin Corp—ISRC partners with Lockheed Martin to support assembly planning, automatic path-planning, and systems integration. In addition to work on the stealth fighter (F-117) (see story, page 8 ), ISRC is developing a coating system for a second fighter jet (the F-22), and is conducting preliminary concept development for a third (the JSF).

• ETI—A military contractor, ETI is licensed to produce and sell the Sandia-developed RATLER™ vehicle. (see story, page 7 )

• Numotech, Inc.—For this wound research-and-design company, Sandia developed light-weight pumps and inexpensive sensors to produce a technology military organizations can use in the field. The technology provides care without the presence of a physician. The treatment delivers a healing oxygen bath to wounds. A previous ISRC-Numotech partnership developed an intelligent wheel-chair cushion.

• Automotive and ship-building industries—On a proprietary basis, ISRC develops automated manufacturing, especially related to sensor-aided and flexible (low-volume, high-precision) manufacturing.

• Military—In general, ISRC partnerships with military organizations provide conceptual development, pilot production, and support commercialization. Some examples: battlefield robotics, automated logistics, and custom manufacturing.

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AGGDIS must align spanner and socket wrenches with components, unscrew threaded components, pour and handle sensitive igniters.

## Robotic Technologies for Hazardous Environments

These robotic capabilities are designed to detect and handle explosives and to work in radioactive or other toxic environments without endangering humans.

• AGGDIS—Automated Gas Generator Disassembly—takes humans out of harm's way. This robotic technology dismantles explosive gas generators removed from nuclear weapons. Automated disassembly produces uncontaminated products that can be recycled. AGGDIS removes a threaded locking ring and a closure disk, pours out and dislodges any remaining propellant, removes the threaded igniter, and places it on a pallet.

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• ARMMS—Accident Response Mobile Manipulation System—will ensure that people are not endangered during the recovery and remediation activities that follow a nuclear accident. A sophisticated response unit, ARMMS combines the mobility of a Humvee military vehicle with robotics technology to conduct salvage and recovery tasks. ARMMS can be teleoperated over a distance of four kilometers. A mapping-and-sensor suite detects and locates radioactive debris and hazardous gases. A command-and-control center has a zoom-lens camera mounted on a 20-foot mast. The camera monitors the Humvee system and provides general surveillance of the area.

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ARMMS technologies include manipulator arms with a lifting capacity of 250 pounds. The unit has a navigation mapping system with global positioning system, and an all-weather command-and-control shelter with its own power source.

Sandia researcher Rich Diver checks out the prototype of the 10-kW Solar Dish/Stirling Remote Power System. A version of the solar collector will be placed on Indian lands in the Southwest where it will pump water for agricultural purposes.

# SANDIA TO JOIN FORCES WITH NATIVE AMERICAN TRIBES IN TESTING NEW SOLAR-ELECTRICITY GENERATING SYSTEM

Sandia National Laboratories will join forces early next year with one or more Native American tribes in the Southwest to test a new solar-electricity generating system that will power a water pump for agricultural use.

A prototype of the 10-kW Solar Dish/Stirling Remote Power System consists of 500 square feet of mirror collector panels and an engine that converts solar energy to electricity. A second-generation prototype planned for this fall will drive a conventional water pump. The first solar pumping system to be erected on an Indian reservation should be operating by early 2001.

"This new solar system is designed to provide power in remote areas for such applications as pumping water, operating a mill, or providing power to a remote village," said Craig Tyner, manager of Sandia's Solar Thermal Technology Department. "It will be small enough and, at a price of $30,000 to $40,000, affordable enough to be practical."

Tyner said international markets probably will be most interested in the system, although it might also be used in rural areas in the United States.

Sandia representatives are talking to several tribes in Arizona and New Mexico about installing demonstration systems on their lands. Sandia will work closely with the tribes to train operators and maintenance personnel.

The new remote power system is being developed as part of the Department of Energy's Concentrating Solar Power Program, which is providing the funding.

To generate electricity, the sun-tracking mirrors concentrate sunlight onto a receiver that sits on top of a platform extended about 18 feet from the mirrors. The receiver collects and transfers the sun's heat to the engine. Helium fills the sealed-system engine. As the helium is heated and cooled, its pressure rises and falls, causing the engine pistons to move and produce mechanical power. The mechanical power in turn drives a generator and makes electricity.

Diver said the solar technology will be transferred to industry partners over the next few years. These suppliers will plan and implement international manufacturing, marketing, sales, and support efforts. Previous studies by U.S. industry have estimated markets for this type of remote system to be several billion dollars per year.

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• RETRVIR—REmoteTeleRobotic Vehicle for Intelligent Remediation—is a robotic manipulator for use in hazardous situations. Mounted on a Honda all-terrain vehicle, RETRVIR can locate, excavate, and remove unknown and potentially hazardous objects from a site by using advanced sensor-based, graphical-control technology. The vehicle is operated remotely. The robotic arm can dig and lift up to 250 pounds.

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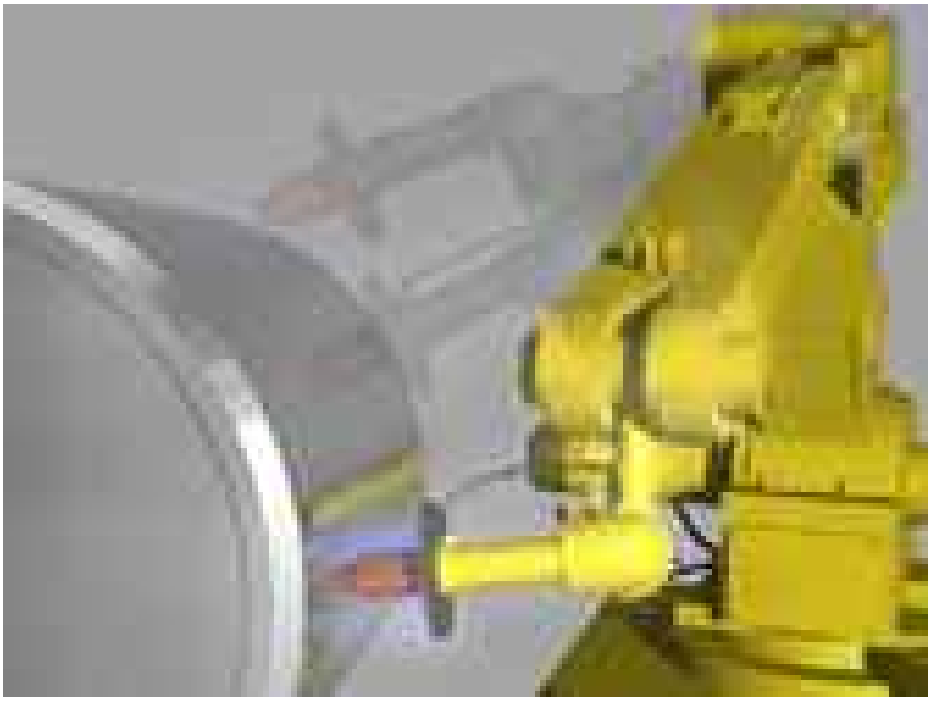
RETRVIR deposits an uncharacterized object from Sandia's explosive test site.

## World Modeling Technologies

Robotics and intelligent machines are constantly solving new problems and are in increasing demand for a growing number of applications. Rapid world modeling allows robots to navigate and manipulate safely and efficiently within unknown and highly unstructured environments.

The following technologies span needs such as accident and emergency response, surveillance and reconnaissance in urban terrain, and disabling improvised explosive devices.



A LAMA system has created a world model of a partially buried barrel. The model, completed in about six minutes, enables the graphical planning, programming, and simulation of a robot taking a swipe survey along the barrel's dented portion.

• LAMA—LAser MApper—system uses a camera and a plane of laser light to create 3-D models of objects it senses. The system eliminates image correlation problems associated with stereo cameras. LAMA also can map building interiors.

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• SRI—Scannerless Range Imager—uses modulated laser floodlight illumination, gain-modulated image-intensified CCD cameras, and unique digital processing methods to create 3-D range imaging.

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## Rapid Prototyping and Systems Analysis

Government and industry need rapid prototypes to understand how robotics and intelligent machines can support other technologies and concepts before allotting large sums of money to new programs. Sandia's rapid prototyping capability employs computer simulations and computer-based machines to perform experiments and demonstrate the feasibility of new concepts as well as analyze performance.

• AMPS—the Agile Manufacturing Prototyping System—allows manufacturers to quickly update and reconfigure production processes. AMPS develops and tests agile-production processes and their integration into existing manufacturing cycles. The system offers flexible-manufacturing hardware and software that incorporate advances in sensor and model-based control, automated assembly and task planning, and automated reconfiguring.

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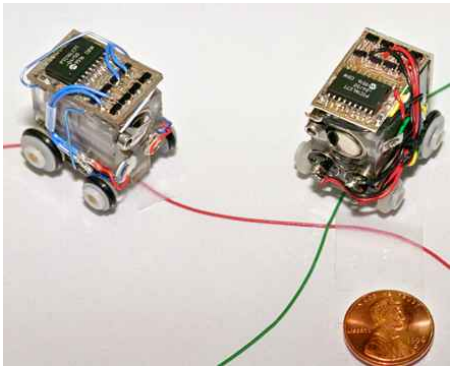

The first of its kind, MARV paves the way for small vehicles with mobility, intelligence, on-board navigation and communication, and the capacity for cooperative behavior.

• MARV—Miniature Autonomous Robotic Vehicle—is a product of Sandia's Small, Smart Machines program that designs, manufactures, and tests mini- to micromachines. MARV is one of the world's smallest autonomous vehicles. Measuring one cubic inch, the minirobot carries power, sensors, a computer, and all necessary controls on board to locate and track buried wires that carry radio signals. MARV technology is a test bed for evaluating critical subsystems of future autonomous vehicles.

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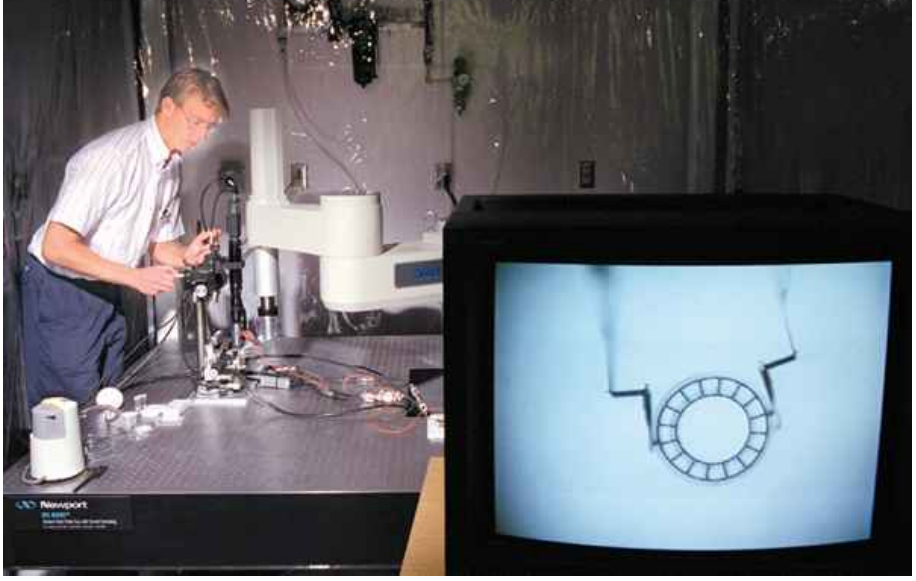
AMPS allows industrial users to test system-level concepts for flexible automation. University researchers can test ideas in an environment that reflects the complexity of a factory.

• MegaLab and the MicroManipulation Lab both investigate, develop, and test rapid prototypes. MegaLab supports the manufacturing processes for large (tens of feet) or heavy (hundreds of pounds) equipment. The facility can be quickly and inexpensively reconfigured as needed for different applications, such as an integrated group of unit process cells, advanced material handling, or manipulation of large or heavy objects. MegaLab also is developing software for virtual manufacturing.



The MicroManipulation Lab offers motion-control equipment including a robotic work cell with 40-nanometer position resolution; long-distance microscopes; laser-interferometer equipment; an automated precision agile assembly work cell; and real-time computervision to control mechanisms and motors for alignment and assembly of parts with submicron tolerances.

The MicroManipulation Lab addresses the automated assembly of microelctromechanical systems (MEMS), or parts that measure 10 to 100 microns (the diameter of a strand of hair).

- PML—the Precision Metallization Laboratory—characterizes, models, and deploys high-energy, automated manufacturing processes (such as welding, plasma spray, laser cutting, heat treating, and ablation) to streamline manufacturing, accelerate production, and monitor and adjust processes as necessary. PML integrates advanced manufacturing path-planning software with real-time, sensor-based control. Lab results can determine how feasible an approach is; which fabrication capabilities will lead to a better product or process; and what processes will ensure rapid, high-quality, and cost-effective design.

***The Department of Energy has used PML to design and produce highly reliable containers for safe, secure transport and storage of nuclear materials.***

# NEWS

## Notes

### SANDIA NATIONAL LABORATORIES PRESENTS FULLY INTEGRATED LAB-ON-A-CHIP DEVELOPMENT

Sandia California is developing a powerful new portable chemical analysis device that fits in the palm of a hand.

"People have been talking about this for a long time," said former Sandia chemist and presenter Christopher Bailey. "It integrates all the pieces."

Quick, sensitive, and selective chemical analysis on a chip, not tethered to large lab equipment, is expected to become affordable and widespread through future developments. Researchers envision automated, field-portable systems, producing results in real time that could sniff out land mines, determine food quality, check environmental safety for emergency responders who suspect chemical or biological hazards, detect pollutants near their source, perform medical diagnostics at a bedside, screen new pharmaceutical drug candidates, or optimize industrial processing.

Sandia researchers have demonstrated the device's capabilities by analyzing a complex mixture of explosives. A chemical signature—or fingerprint—was created by separating constituents with chromatography, a process of moving the mixture through separation channels containing a variety of materials.

Sandia's hand-held, integrated device for analyzng liquid and gas mixtures.

The materials retain constituents to different extents, so constituents appear sequentially in separate batches at the end of the channel. From an initial mixture injected manually into a reservoir, the system automatically distributes a fraction of a droplet (a tenth of a nanoliter) to channels thinner than a human hair. Within about a minute, a small display screen flashes the name and quantity of the components.

The technique detects compounds at the part-per-billion level. The process involves shrinking and knitting together disparate systems, and replaces standard chemical-analysis methods normally performed with bulky equipment on a laboratory countertop.

The hand-held chemical-analysis device includes a compact power source and solid-state relays that regulate and switch energy drawn from camera batteries. Built-in lasers and photodiodes, fabricated in a bit of semiconductor that would fit easily into a pencil eraser, read results in each of three channels. Results are analyzed by an internal microprocessor that also automates the separation. To program the microprocessor, users toggle through a menu of commands using four buttons on a touch pad.

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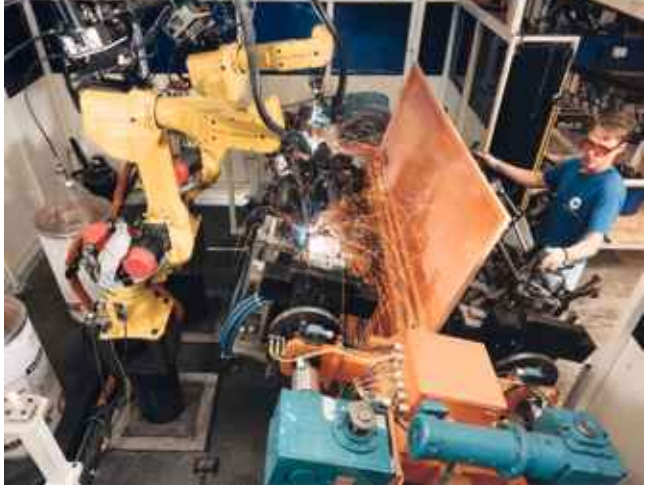


# RIM INDUSTRY BOOMS

The North American robotics industry enjoyed its best year ever in 1999. Through September, a total of 13,368 robots valued at $1.11 billion had been ordered, a 62-percent increase in units and 40-percent hike in dollars over the previous year.

"The United States Postal Service ordered some $66 million worth of robots," said Donald A. Vincent, the Robotic Industries Association (RIA) executive vice president. "There's also been an increase in the use of robots in industries, such as food, consumer goods, and plastics, while demand for automotive manufacturers and their suppliers remains strong."

The industry continued to grow through the end of 1999.

"Spot welding robot orders skyrocketed 102 percent, assembly robot orders jumped 100 percent, material handing was up 52 percent, and arc welding grew 46 percent," Vincent said. "The vast majority of the new orders were placed by North American manufacturing companies seeking to improve productivity, increase flexibility, speed time to market, and boost quality. North America is the hottest robotics market in the world."

Material handling applications have emerged as the leading use for robots, followed by spot welding, arc welding, assembly, material removal, coating, dispensing, and inspection. The RIA estimates there are about 100,000 robots in use in the United States. According to industry analysts, fewer than 10 percent of the manufacturing companies that could benefit from robotics have installed robots, presenting a huge, untapped market for robot suppliers.

***"The vast majority of the new orders were placed by North American manufacturing companies seeking to improve productivity, increase flexibility, speed time to market, and boost quality. North America is the hottest robotics market in the world."***

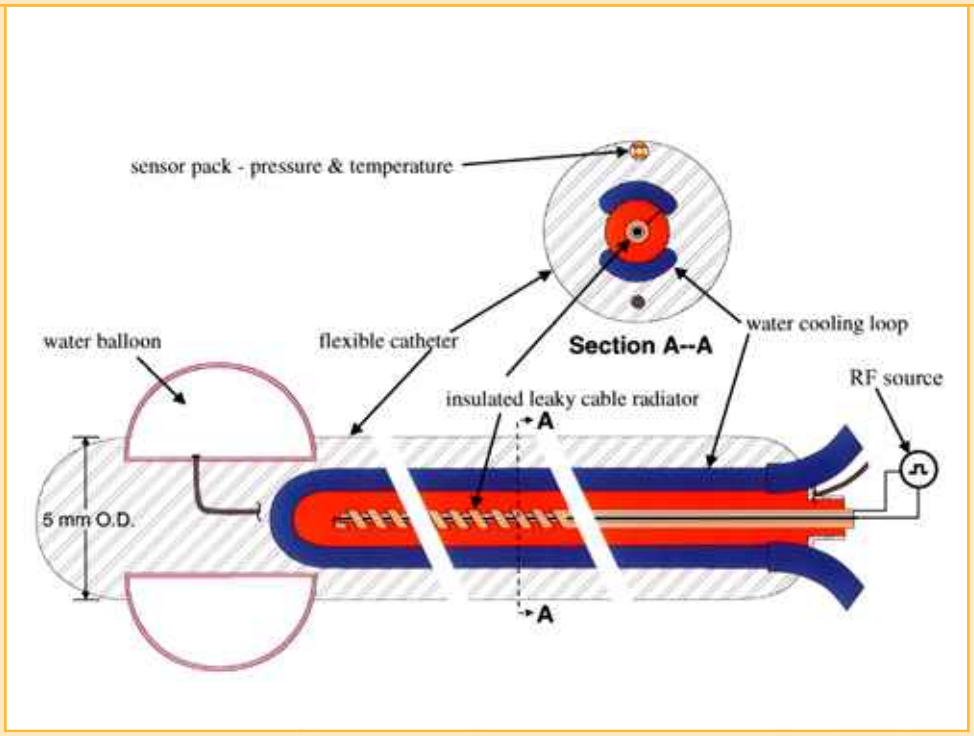
The following areas have been identified* as poised to benefit from robotics algorithms and technologies:

- Elderly and handicapped people
- Material handling systems (such as forklifts, bulldozers, and item pickers in conveyor systems)
- Food preparation and serving systems for fast foods, butchering beef, and cleaning and cutting chicken and fish
- Waste handling, to improve autonomy and efficiency, especially in hazardous environments
- Law enforcement, especially for stealthy operations
- Construction, to assist with automated or partly automated construction of nonstandard buildings, industrial plants, and airports. There also is a need for teleoperated or autonomous systems in mining and sandblasting
- Entertainment, to assist human-operated systems in camera movement and set placement
- Other industrial applications, for inspection and maintenance in factories and warehouses, and teleoperated or autonomous printing systems

**From a 1996 report by George A. Bekey, "Needs for Robotics in Emerging Applications: A Research Agenda" presented to IEEE/RIA workshop supported by the National Science Foundation and the Department of Engergy.*

# NEWS Notes

## SANDIA PHYSICIAN DEVELOPS IMPROVED METHOD TO SHRINK ENLARGED PROSTATE GLANDS WITHOUT SURGERY




A recently patented radio-frequency "leaky-wave" applicator will deliver a uniform heating pattern along length of the prostate gland to treat benigh prostatic hyperplasia (BPH).

Millions of older men who suffer from urinary obstruction and associated pain caused by an enlarged prostate gland could benefit from a new treatment technology developed by a senior scientist and physician at Sandia National Laboratories.

Current treatment methods that use drugs, surgery, and other devices are effective to various degrees in arresting this condition—benign prostatic hyperplasia (BPH)—but the method developed by Sandia's Dr. Lawrence Larsen should have several advantages. The method could be performed on an outpatient basis, and a single treatment should have long-lasting benefits, perhaps for the life of the patient. Also, side effects should be almost nil from the minimally invasive technique, and treatment costs could be lowered, Larsen said.

His new endoscopic method uses an improved radio-frequency (RF) "leaky-wave" applicator to deliver a uniform heating pattern along the length of the gland. The process shrinks the prostate by killing excess cells that typically grow as men age. The uniform heating pattern is a major improvement over some existing treatment devices. A patent was issued for this technology in April.

Now that the patent has been issued, Larsen says the next step will be to partner with the medical device industry and clinical centers to manufacture and test the technology on humans. The Urology Department at Albuquerque's Veterans Administration Hospital is a potential clinical partner, he says, and preliminary discussions have already been held with doctors there.

Larsen's technology is designed to treat benign prostate enlargements that cause urinary obstruction and pain, not cancerous problems. BPH does not necessarily lead to prostate cancer, he says, but is loosely coupled.

This work is a product of Sandia's Laboratory Directed Research and Development program as a dual-use application of radar technology and conformal antennas. The research is related to the lab's projects in applied electromagnetics that affect diverse technologies, including communications, microwave-power electronics, proximity fuses, and directed energy.

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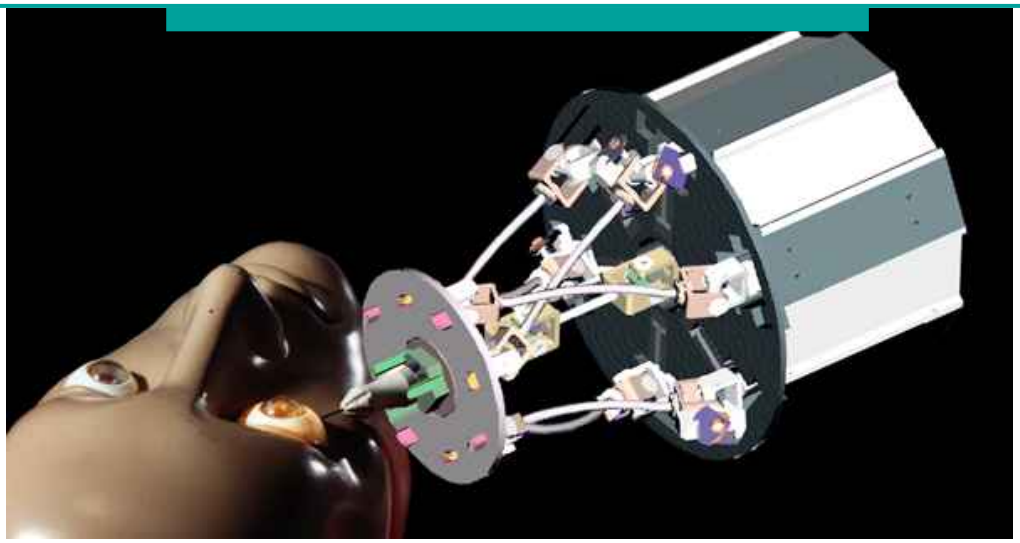
# *From Medicine to Movies, Robotics Will Populate*

# Tomorrow's World



Terrorism, aging populations, climate change, and scarce resources challenge the world today. But intelligent machines may help resolve these and other social, environmental, and defense-related problems.

Under the guidance of Sandia National Laboratories Vice President Gerold Yonas, the Labs' Advanced Concepts Group is researching future risks to the United States to find solutions. At least part of the answer, Yonas said, will come from robotics and intelligent machines (RIMs).

Intelligent machines very likely could spark the next revolution, said Yonas, the Labs' principal scientist.

In the area of health care, a robotics pulse, temperature, and blood-pressure monitor could be fit into a watch or on a pair of eye glasses, allowing elderly people to live at home with greater independence. A non-invasive blood-chemistry monitor might provide real-time diagnosis. Information from these monitors would be sent to a central computer, and a physician could then check on the patient after being alerted by the computer. Such home healthcare monitoring robots also could be connected to other robots that dispense pills or even prepare meals.

Yonas predicts that in 20 to 30 years intelligent prosthetics will enable the blind to see, the deaf to hear, and the confused or forgetful to think more clearly. An intelligent patch may repair spinal injuries. These technologies will not replace but assist failing body parts.

On future battlefields, mobile robots will someday largely replace soldiers. The robots will work together to seek out and destroy the enemy, saving both lives and money. When faced with future terrorist acts, such as the release of a biological weapon in a city or on a battlefield, robots with biosensors will immediately identify the nature of the weapon and alert humans to take precautions.

Manufacturing: RIMs are established features in many industries already. Commercializing outer space represents yet another RIM frontier.

Environment: Pollutants—monitored by satellites or flying robots—will also be investigated by robots. Or an unmanned aerial vehicle could drop probes into contaminated areas for monitoring.

Entertainment: A robotic guide could lead people on a tour of an amusement park and keep track of those who wander off.

But these advances could have mixed blessings. Yonas warns that intelligent machines could become readily available and even purchased commercially and turned against anyone. Robots that are as small as insects could go unnoticed as they deliver chemical or biological weapons to unsuspecting individuals, he said. In other words, robots themselves could become an emerging threat.

# VIRTUAL CENTER PROVIDES COMMUNITIES WITH ASSISTANCE IN TERRORISM-READINESS

Sandia researcher Grant Lockwood holds a laboratory version of his off-the-shelf X-ray source to safely examine the insides of containers that could conceal bombs. Shown in the already opened box are two simulated sticks of dynamite, a timer, and a detonator.

Government and business officials responsible for safeguarding their communities or companies against the threat of a terrorist attack have a new resource: a virtual-information center at Sandia National Laboratories.

The center, which can be reached over the Internet or by phone, can provide advice on how to improve security against terrorism and provide facilities with features to mitigate an attack in progress.

Called the National Institute of Justice's Center for Civil Force Protection (CCFP), it can provide objective information about and assistance in identifying:

- Methods to "harden" buildings or other structures against attack
- Technology to detect and mitigate explosives or chem-bio warfare agents
- Vulnerability and consequence assessments for a facility's physical security
- Consulting and training methods to improve security against terrorism
- Organizations that provide terrorism preparedness

The National Institute of Justice (NIJ), the research arm of the Department of Justice, asked Sandia to establish the CCFP to provide a means whereby state and local law-enforcement agencies could access this type of expertise.

Through the virtual center, Sandia will draw on its counterterrorism work for federal agencies such as the Department of Defense and the Department of Energy. Sandia also will draw on the facilities and capabilities of the National Law Enforcement and Corrections Technology Center (NLECTC) established by NIJ's Office of Science and Technology. The NLECTC system offers support, research findings, and technology expertise to help state and local law-enforcement and corrections personnel do their jobs more safely and efficiently.

As the lead DOE lab for protecting U.S. nuclear weapons materials and facilities, Sandia has nationally recognized expertise in such areas as physical security technologies and approaches, security-vulnerability assessments of government and private facilities, building bomb and sabotage resistance, remote bomb-disablement technology, security and law-enforcement product evaluation, and school security.

The CCFP can help law-enforcement officials, state and local government officials, public-safety officials, company officials, school administrators, church leaders, community-center directors, and others. (Although most CCFP advice is free, there may be fees or in-kind contributions associated with certain long-term services.)

The Center for Civil Force Protection (CCFP) can be reached on the Web at www.mnlectc.org/ccfp or by phone at 1-888-577-4849.

# INSIGHTS

*by Patrick J. Eicker, Director,*
*Intelligent Systems and Robotics Center, Sandia National Laboratories*

Imagine a world where smart cars avoid collisions; where surgeons guide molecularly precise instruments instead of hand-held scalpels; where satellites the size of marbles monitor rogue nations; where grasshopper-size sensors surveil a battlefield. A world that tackles problems from the galactic to the microscopic—with adaptive machine intelligence.

Imagine assembly workers and machines working in concert to dramatically increase national productivity—the most basic measure of national competitiveness.

Imagine whole industries arising from the creative use of sensors, software, machines and computers—intelligent machines—solving seemingly intractable problems, providing undreamed new products, exemplifying strong bonds between workers and their companies. Imagine the industry that will grow in support—the intelligent-machines industry—providing new software, sensing and machine products. These industries promise a revolution as profound as that of the computer. They will create high-skilled, high-paying jobs that in turn provide additional revenue resources that can be applied to our nation's most pressing problems. The industries will greatly enhance worker and environmental safety and dramatically increase product reliability.

When Sandia, for reasons of improved worker health and safety, was first asked by the Department of Energy to work on robotic systems to dismantle nuclear weapons, many people doubted it could be done.

It was a tough challenge. It meant we had to come up with a machine that had enough computer smarts to safely handle extremely difficult and delicate tasks—tasks that people do so well. It meant we had to draw upon our math, physics, and computer-science capabilities to develop just the right amount of machine intelligence—in this case, the robot equivalents of eyes and touch.

Today, DOE is using Sandia-developed intelligent systems to dismantle, store, and surveil nuclear weapon components. People direct the activities—without being exposed to harmful materials.

NASA is using intelligent machines, such as Sojourner, to provide insights into our planetary neighbors. Micromachines, sensors, and computers are being combined to create tiny intelligent machines that will do everything a room-sized chemistry lab does today. New assistive devices provide the elderly and disabled with greater independence. Intelligent machines offer tremendous potential for humans and the economy. Representatives of transportation, health care, agriculture,

***Today, DOE is using Sandia-developed intelligent systems to dismantle, store, and surveil nuclear weapon components. People direct the activities—without being exposed to harmful materials.***

space exploration, communication, manufacturing, environmental management, the military, law enforcement, national security, and the entertainment industry have all expressed interest in intelligent machines. This diverse group has a shared vision whereby their needs become solvable by a common technology.

Electronics manufacturers have expressed a need for intelligent systems that will rapidly adapt to a changing product line. The auto industry needs systems with human-like dexterity for assembly and materials handling. Food processors want advanced robots with sophisticated meat-cutting and carving capabilities. The agriculture, construction, and mining industries need driverless machines with sensor-based controls for use in the field.

For decades the idea of machines functioning intelligently as capable agents of human operators has captured the imagination of scientists, writers, and futurists. Now these machines are becoming reality.

America leads the world in state-of-the-art advanced sensor devices and intelligent control systems—the core elements of the intelligent machines industry. This leadership exists, in

*continued*

significant measure, because our government has made large investments in intelligent-machine technologies for national security and space exploration, and investments in basic research in American universities. As a nation we must now work together to integrate this investment to create new jobs, new wealth, and exploit the tremendous opportunities that lie ahead.

We have used the term intelligent-machines industry—How big will this industry be? There is an apt comparison between the state of the intelligent-machines industry today and the personal computer of the late 1970s and early 1980s. Many visionaries were part of creating that history. Today the PC hardware and software market are estimated at $200 billion to $400 billion per year. Did the founders know they were creating a market this size? Almost certainly not. Similarly, intelligent machines will create an economic force, and change how we live. This vision has inevitability. The real issue is who will bring it about?

National test beds could accelerate the leadership of a U.S. intelligent-machines industry. Test beds would pool U.S. preeminent research resources, provide focus to otherwise fragmented activities, and bring together diverse knowledge from industrial users, their workers, and suppliers of intelligent-machines technology.

National in scope, these centers would be available to industry, labor, academia, and government, allowing shared benefits of precompetitive testing and development in realistic environments and shared costs. Test beds would align the needs of U.S. companies with those of universities, government, the workforce, and the wider community. They would assure the United States a position of leadership in the field of intelligent machines.

Demonstrating technologies in a realistic environment is critical. Many companies need a bridge between research and applications. Many would opt for fundamental changes if they could see proof-of-concept applicable to their environment. National test beds could prove that intelligent machines work in new applications. National test beds could enable our nation to maintain its role as the world's most productive and technically advanced society, and improve our competitive position in the world economy. We can make this new industry an American industry.

To succeed we must accelerate development. Emerging intelligent machine technologies will open new markets with multibillion–dollar revenue potential. These technologies will help ensure our national security against various emerging threats. Intelligent machines will improve productivity in the manufacturing and service industries. They will create skilled, high-paying, safer jobs for American workers, and enable U.S. companies to maintain a more stable leadership position in the global economy. Intelligent machines will protect employees from hazardous working conditions, augment highly skilled specialized labor, and provide alternatives when labor is scarce.

Will America lead? Or will we let the opportunity slip through our fingers and let other nations reap the benefits? Speed is paramount in today's environment of leapfrogging technology. America still has a choice, but perhaps not for long. One thing is certain—failure to act quickly will relegate the United States to a consumer rather than a provider.

It can happen again. In the 1970s and 1980s the United States lost much of its robot and machine tool industries to overseas competitors. Today our technology leadership in advanced sensor devices, software, and intelligent-control systems—the building blocks of intelligent machines—has given us a temporary advantage. Many industry executives, as well as university and national-laboratory researchers, are urging the United States to seize this short-lived opportunity to lead the intelligent-machines industry. We must cooperate to compete.

The DOE has responded to this challenge by developing a Robotics and Intelligent Machines (RIM) Roadmap which integrates its diverse needs for RIM in manufacturing, environmental management, and nuclear-materials monitoring. This 20-year roadmap structures the technology-development path required to achieve specific goals related to worker safety and cost reduction. The roadmap has inspired unprecedented cooperation among DOE's laboratories, plants and sites, and also has resulted in a new level of interagency cooperation.

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000

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