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Opening Doors to America's Future

Sandia National Laboratories

Opening Doors to America's Future

Intelligent Systems & Robotics Center

The Visions of Dreamers and Doers

The assembly of electromechanical devices smaller than a grain of rice. Repetitive tasks that eventually harm the health of workers. Hazardous environments. A nearly imperceptible tremor in a surgeon's hand. Slow and costly prototyping that keeps an industry a step behind foreign competition.

Diverse and complex, these real-world problems and a national security mission are the challenge Sandia National Laboratories Intelligent Systems and Robotics Center (ISRC) tackles by melding visionary research with bold application of technology. Created with a mission to establish a world-class research and development capability that nurtures and advances the evolution of intelligent systems, the ISRC moves beyond gee-whiz research and theoretical speculation to solid, workable solutions to tough—sometimes seemingly impossible—problems in environments ranging from the operating room to the manufacturing floor to the battlefield.

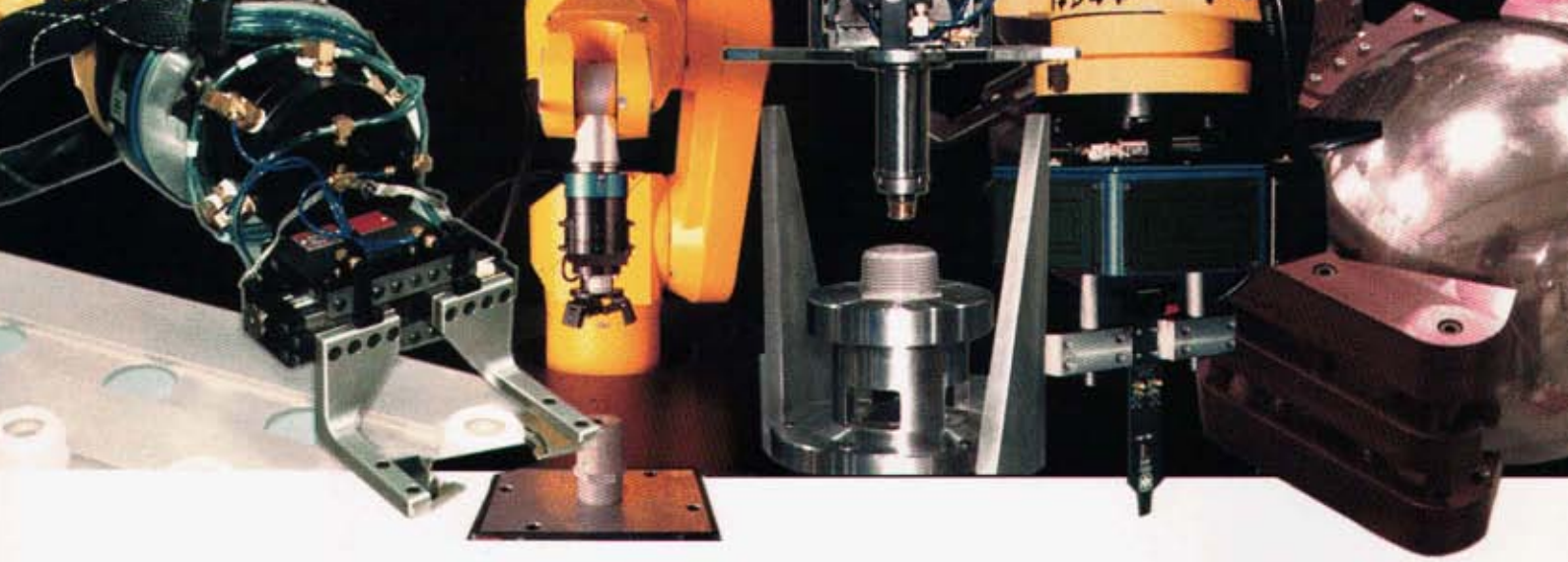
Robots & Intelligent Systems: The Myth and the Reality

For decades the potential of machines functioning in an intelligent capacity, or as the capable agents of human operators, has captured the imagination of scientists, writers, and dreamers. The term "robot" has become almost an archetype, conjuring up notions of machines possessing human personality traits from charming to malevolent: the Star Wars C-3PO robot, complete with affected British accent and a utilitarian accomplice robot, R2-D2 to perform the rote or dangerous tasks. The omnipotent "intelligent system" HAL, in 2001: A Space Odyssey that put completion of the mission above the lives of the crew members.

Now, as 2001 actually draws near, robots and intelligent systems bear little resemblance to what science fiction and popular culture projected

The mind is capable of anything—because everything is in it; all the past as well as all the future.

–Joseph Conrad



The word robot comes from a story and play produced in 1921 called R.U.R. (for Rossum's Universal Robots), by Karel Capek. In Czech the word robot means "worker," but the English translation in 1923 retained the original term.

them to be like at the beginning of the new millennium. And, the science fiction expectation of what robotics technology can accomplish is far different than what the technology has accomplished. That's because the goal of real-life robotics and intelligent systems research today is not to create machine mimics of living organisms, but rather to develop highly specialized tools—tools that extend or enhance human physical capabilities; tools that work in place of people in hazardous environments; tools that increase the speed, accuracy, and efficiency of manufacturing and industrial processes; and tools that will solve problems that are at the present time unsolvable.

So, this is the challenge of the ISRC: As a premier robotics and intelligent systems research organization, bring the technology to a level of maturity that transforms science fiction to science fact.

Leaping the "What if" Boundary

In the current state of technology, robotic devices are quite accomplished at repetitive tasks in mass production such as welding trunk hinges on a specific model of car or installing batteries in a specific model of cellular phone. The robot performs a very limited set of identical actions on identical parts, each of which is delivered to the robot in a well-defined and narrowly constrained location.

RETRVIR (pronounced "retriever") is able to perform tasks in hazardous environments, reducing risks to workers.

And while there is still much refinement and enhancement to be accomplished in the world of mass production, it's the "what if" boundary that intelligent systems technology must now leap: What if each car is unique? What if each phone is shaped to fit the buyer's hand? This is called mass customization, one of the new frontiers of robotics and intelligent systems technology—a frontier where Sandia's ISRC is a leading pioneer.

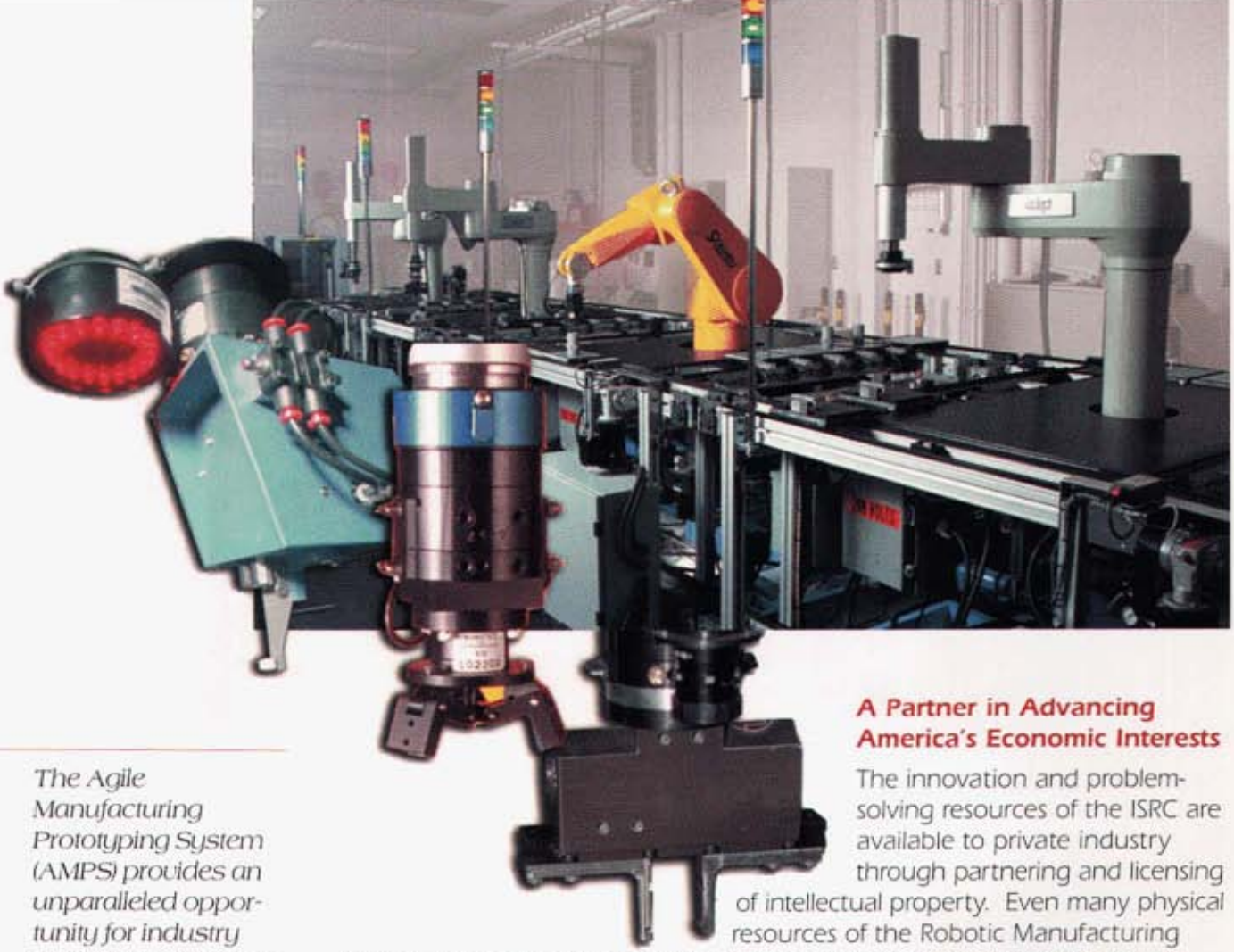
Manufacturing and industrial environments—even those where mass customization will be at work—are still relatively structured. This differs from the world people encounter in daily life, an unstructured environment that requires we react, interact, and make countless decisions. It is the unstructured environment that roboticists regard as the greatest challenge, and it is the unstructured environment that is the arena for some of the ISRC's most visionary goals and innovative accomplishments—accomplishments as diverse as robotic systems that can negotiate the complex terrain of a waste site and perform remediation tasks, or microsurgery instruments that prevent the accidental incision of nerves or blood vessels.

Robots and intelligent systems based on ISRC technology are currently hard at work in the hazardous environments of nuclear material handling. Robots and intelligent systems offer the obvious advantage of reducing worker exposure to radiation, but there are many other benefits as well: enhanced security, error-free record-keeping of material access and location, and superior surveillance capabilities. In addition, because the robot does not have to "suit up," contaminated materials associated with workers' protective gear are eliminated, thereby reducing the waste stream.

The ISRC: A National Resource

Fundamental to intelligent systems and robotics development is the seamless integration of disparate technologies. That means bringing together researchers from many different disciplines: physicists; mechanical, civil, nuclear, and electrical engineers; chemists; computer, aerospace and aerodynamics scientists; statisticians; and technicians. More than 150 highly educated, diversely talented professionals work together at the ISRC with the common purpose of advancing the development of intelligent systems and robotics.

The ISRC is a well of information constantly replenished with new ideas and new visions that produce new intelligent systems and robotic solutions to widely varied, real-world problems. We've worked on cars. We've worked on weapons. We've worked on systems that will be used in outer space and systems that can be used in food handling. We've even worked on a better way to sew blue jeans. This depth and breadth of experience and intellectual capabilities, coupled with the Robotic Manufacturing Science and Engineering Laboratory, an extraordinary 73,000-square-foot building designed specifically to house intelligent systems and robotics R&D, makes the ISRC unmatched by any other single organization or facility.



The Agile Manufacturing Prototyping System (AMPS) provides an unparalleled opportunity for industry and academic users to test system-level concepts for flexible automation.

A Partner in Advancing America's Economic Interests

The innovation and problem-solving resources of the ISRC are available to private industry through partnering and licensing of intellectual property. Even many physical resources of the Robotic Manufacturing Science and Engineering Laboratory, such as equipment and computers, are available for use in our partnerships with industry.

But partnering and licensing aren't the only ways the ISRC can help businesses and industry. We can serve as a "skunk works"—an R&D facility with a mission to rapidly explore extremely creative solutions—for the private sector. Even research-intensive companies can benefit from our expertise, especially if a particular problem falls outside their R&D efforts. For example, a high-tech electronics firm might look to us for manufacturing technology to produce high-value, low-cost niche consumer electronics in order to provide the quality demanded by today's consumers.

Firms come to the ISRC for a single project or for a long-term relationship such as a company might have with a most trusted supplier. The contractual processes are in place to make the resources of the ISRC accessible to private industry and ensure the flexibility of our business relationships.

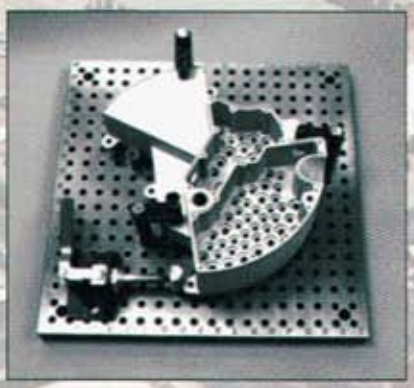
Searching for Problems to Solve

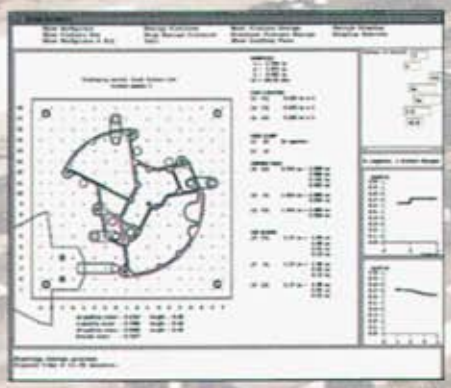
Bring us a problem. The ISRC is a truly market-driven technology development team with the goals of making products or processes "faster, safer, cheaper, or better."

We have successfully negotiated the paths of many complex problems and constantly seek new challenges to stretch our skills. And, if the ISRC doesn't have a solution, the entire depth and breadth of Sandia National Laboratories' collective expertise is available. As a primary provider of the engineering and science needed to assure national security requirements, Sandia has developed numerous technologies that have potential applications in manufacturing, materials handling, medicine, and industry. Making these technical resources available to the private sector is yet another way Sandia National Laboratories carries out its mission of rendering "exceptional service in the national interest."

ISRC Technologies Solving Problems

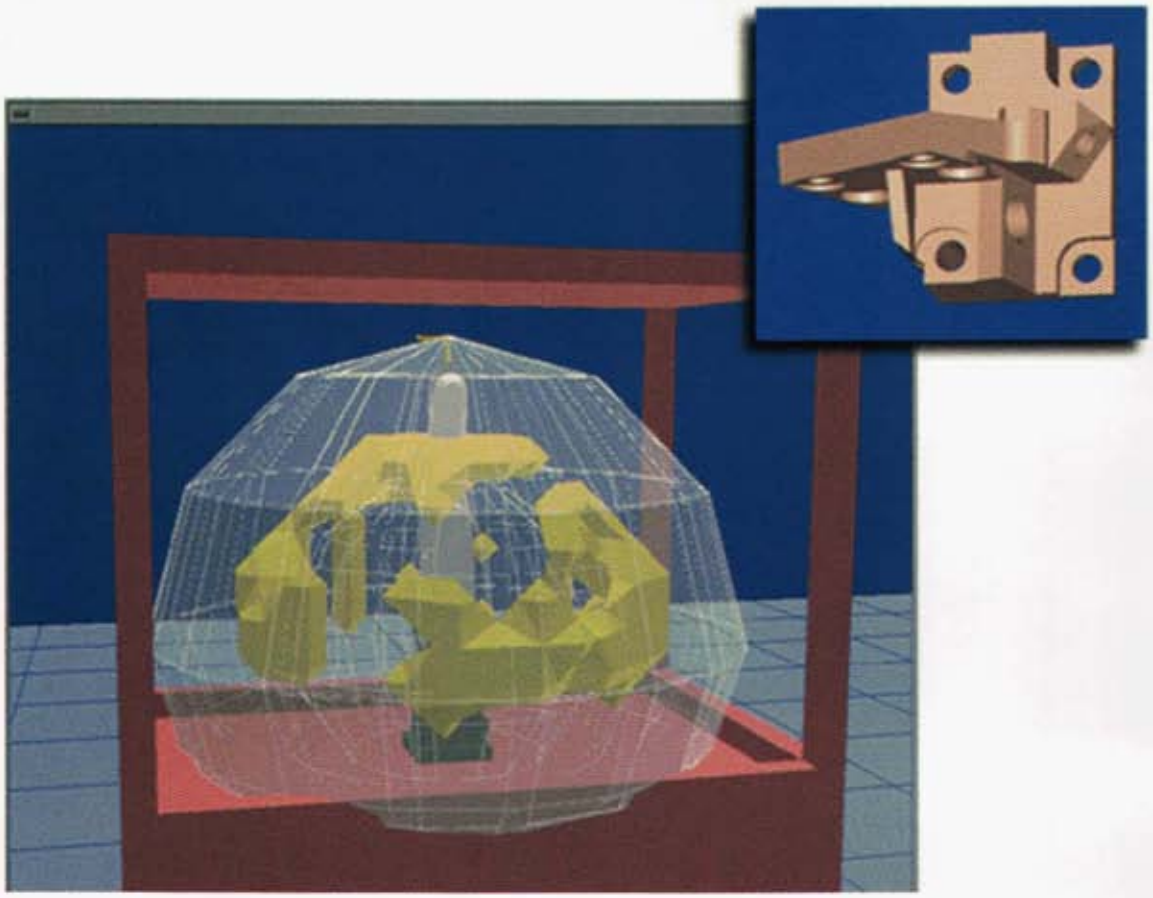
The myriad technologies under development at ISRC fall into three categories: automated planning and programming, the "brains" or reasoning for robots and intelligent systems; sensor and model-based control, the "eyes" that accumulate and interpret data; and technologies of integration, the art of putting it all together, coordinating the hardware, software, and mechanical components that are a robotic device. Here's a sample of how these technologies are solving problems in real-world environments today.





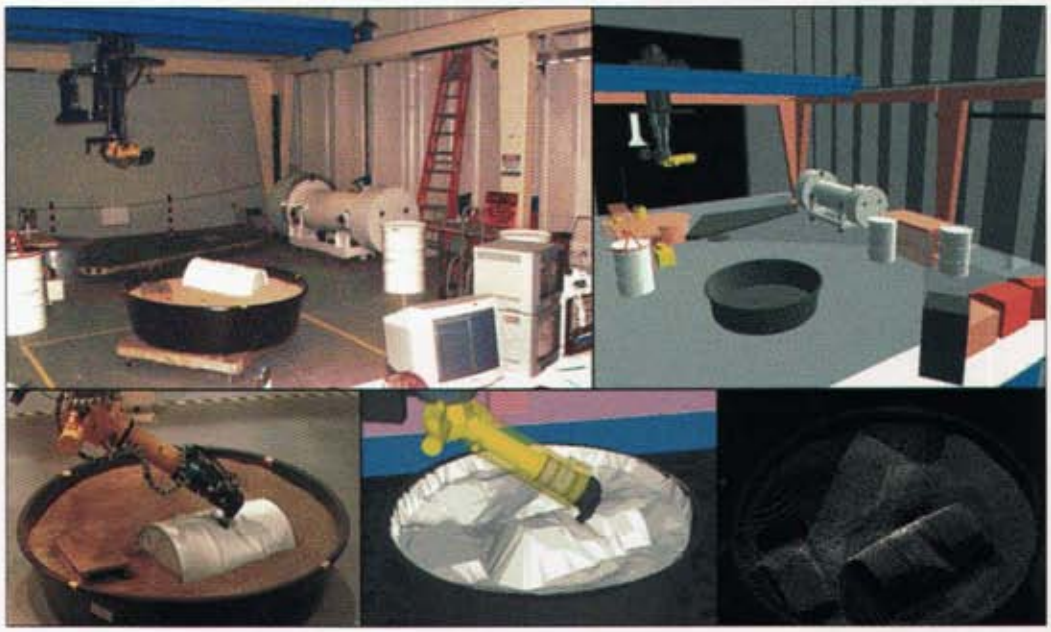
Automated Planning and Programming—Instead of developing tedious step-by-step instructions for an industrial process such as assembling a motor, automated planning and programming technologies build the instructions from input such as a computer-generated model. An example is ISRC's Archimedes. A manufacturing engineer can spend a month planning product assembly. Archimedes reduces this time to hours. Hours. An ISRC customer recently used Archimedes to plan the assembly of a

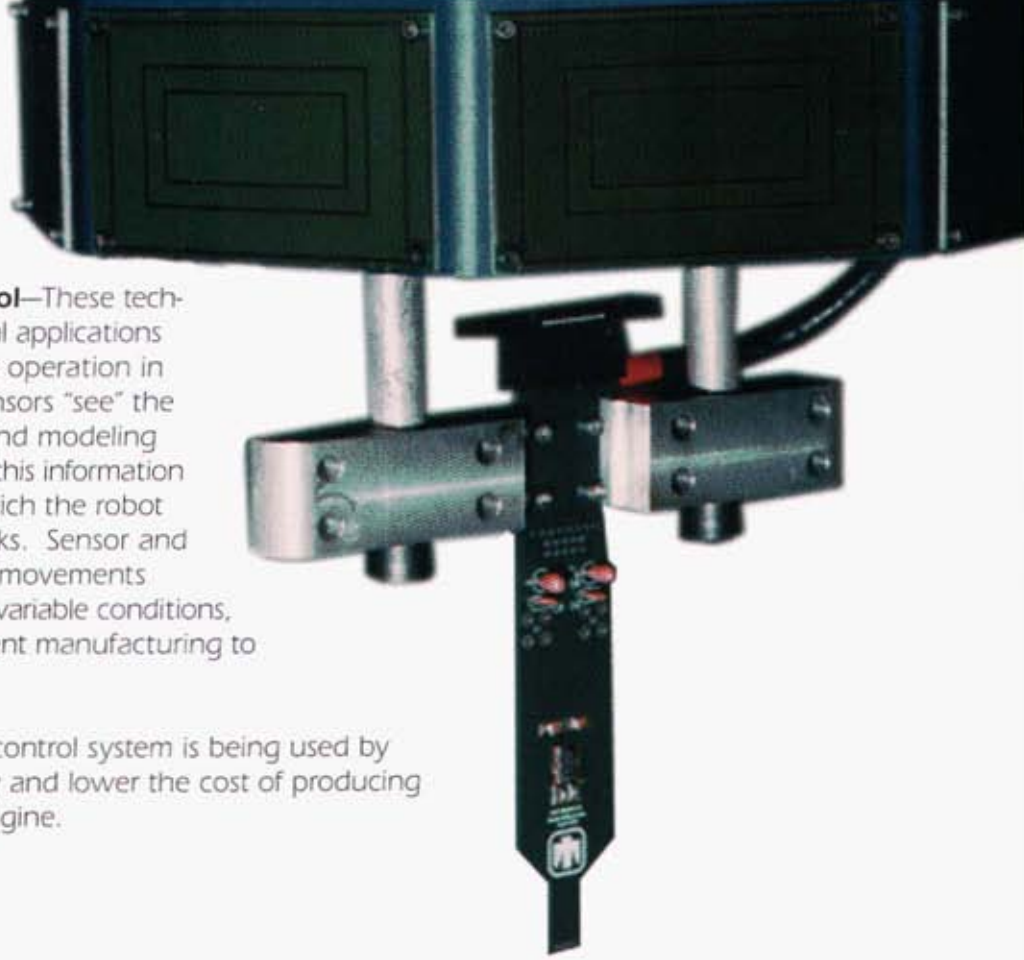
RETRVIR (Remote Telerobotic Vehicle for Intelligent Remediation) may look like every kid's ultimate toy with its Honda all-terrain vehicle body, pivoting roof-top camera, and robotic arm. But it's designed for serious work—environmental cleanup—and embodies all of ISRC's technology development. Sensor and model-based control maps RETRVIR's surroundings to determine how it will maneuver. Miniaturized sensors help RETRVIR locate and characterize contaminants. Automatic planning and programming keeps it from colliding with objects. Technologies of integration make it easy to change RETRVIR's equipment so it can perform new tasks. These technologies also make it possible for RETRVIR to be quickly and easily programmed remotely by technicians with no special computer training.



product with more than 500 parts. The high level of accuracy and precision planning capabilities of this tool were considered a major advantage in the customer's bid to produce this product.

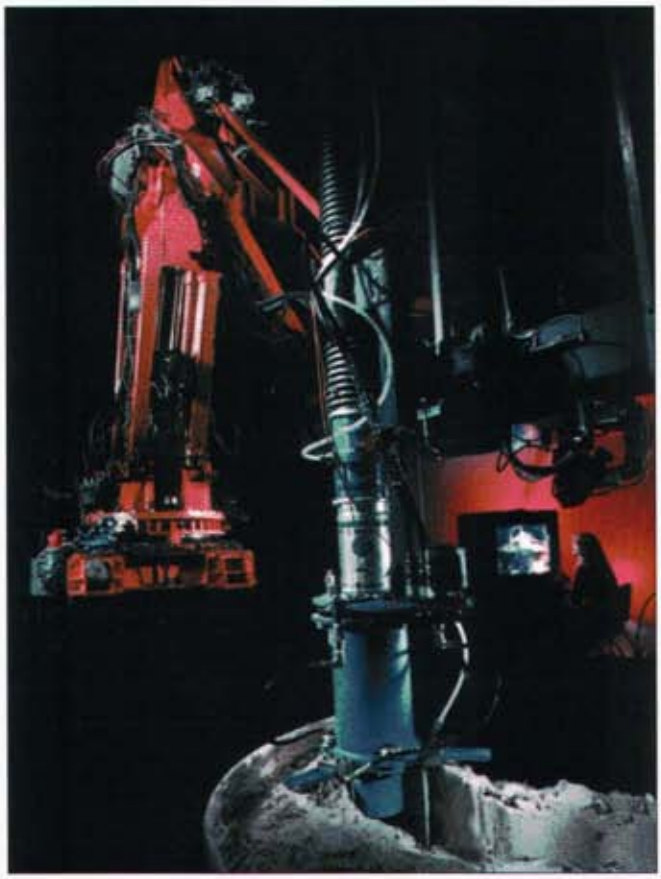
Besides Archimedes, the ISRC has automated planning and programming tools that perform automatic design for fixtures, grippers, and other grasping devices; automatic path planning for robot navigation; and automatic generation of robot vision programs.





Sensor and Model-Based Control—These technologies are the key to the industrial applications of mass customization and robotic operation in an uncontrolled environment. Sensors "see" the terrain in a robot's environment, and modeling software instantaneously translates this information into three-dimensional "maps," which the robot uses to negotiate and perform tasks. Sensor and model-based control defines how movements and operations can be adjusted to variable conditions, from the edge of a seam in garment manufacturing to automated painting.

An ISRC sensor and model-based control system is being used by Rocketdyne to improve the quality and lower the cost of producing the space shuttle main booster engine.



Technologies of Integration—These are the technologies that allow the ISRC to rapidly build systems from the many components we work with. Many of the technologies of integration are software tools that function as adapters to link dissimilar technologies. They can be used to create whole new systems, or increase the capability or flexibility of an existing system. The dissimilar technologies may be other software systems like automated programming and planning system software, hardware-based systems like sensor and model-based control systems, or mechanical devices such as robotic arms and grippers. Each different technology or system "plugs" into the technology of integration tool, which then acts to coordinate, translate, or act on the data fed to it. For instance, an ISRC technology of integration tool called GISC (Generic Intelligent System Control) made it possible to link equipment from six different laboratories to create a completely new system that demonstrated environmental cleanup capabilities. Technologies of integration not only help build systems faster, they also create the flexibility necessary to change the system to meet new needs.

Opening Doors to the Future

Intelligent systems performing tasks that are too difficult or too dangerous for people—or that are currently hindering American competitiveness. This is the vision guiding the work at ISRC. It is work grounded in the fundamental practicality of serving our country's security and advancing the efficiency and competitiveness of U.S. business and industry. ISRC is crossing the technological threshold that separates potential from performance. And we believe that *major breakthroughs in technology are achieved only by those bold enough* to conceive ideas that are impossible to accomplish today, and who pursue them with the determination that they will be possible tomorrow.

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Intelligent Systems & Robotics Center

Fact Sheet

Robotic Manufacturing Science & Engineering Laboratory

Description

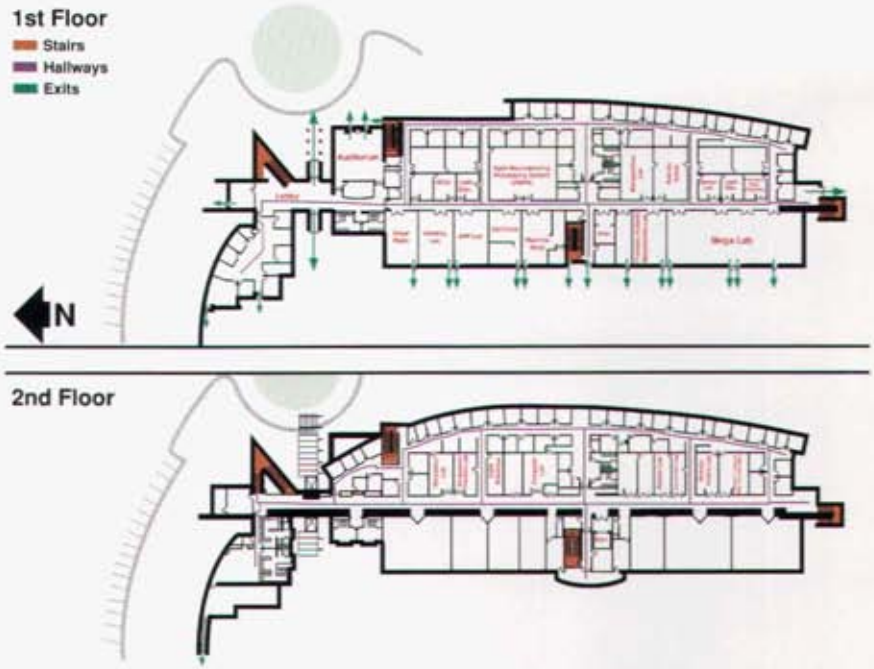
Intelligent systems bring diverse technologies together: computers, software, sensors, vision systems, and hardware such as robots. At Sandia National Laboratories, combinations of these technologies are merged to create robotic and intelligent systems that range from micro to mega. Sandia National Laboratories and the Department of Energy created the Robotic Manufacturing Science and Engineering Laboratory (RMSEL) for the Intelligent Systems and Robotics Center (ISRC) to advance the evolution of robotic and intelligent system technologies. It is the first centralized facility designed specifically for bringing intelligent machine technologies and technologists together.

The 73,000-square-foot RMSEL facility was designed as a special environment to accommodate the unique needs of robotics and intelligent systems research. A second-floor viewing gallery concourse overlooks ground-floor laboratories used for the development of large-scale robotic systems. In addition to staff offices, there is work space for visiting collaborators. Special conference facilities are another way RMSEL provides collaboration opportunities with industry, government, and academic partners.

The state-of-the-art physical resources coupled with outstanding intellectual resources make RMSEL unique in robotic and intelligent systems research and development.

One of the main purposes of RMSEL is encouraging collaborative development with industry and academic partners. In an effort to make its resources as accessible as possible, ISRC has invested in Virtual Collaborative

Engineering (VCE), a matrix of technologies that allows scientists, engineers, technicians, and robotics operators from any location to collaborate with the ISRC staff. Virtual Collaborative Engineering enables collaborators scattered over great distances to efficiently solve complex engineering problems, saving travel time and expense. Using VCE technologies, researchers can test theories, validate models, and advance new control operations in their own labs using the ISRC robots. Designers can access machining centers to fabricate prototypes. Manufacturers can model, simulate, and measure the performance of robotic systems before purchasing them.



By continually refining VCE technologies and developing other processes of value to the private sector, RMSEL aims to be a model of industry, university, and government teaming.

Features

- **High-bay labs for large-scale precision gantry and pedestal robots**
- **An agile manufacturing prototype system for part handling and assembly**
- **Manufacturing processes such as brazing, soldering, welding, and cutting**
- **Labs for assembly of microsystems**
- **Sensor, control, and vision systems**
- **Computer modeling and simulation capabilities**
- **Remote intelligent vehicles**
- **Virtual reality environments**
- **Outdoor test area for mobile robotic experiments such as demining, waste remediation, or construction**

Stage of Development

RMSEL is in the final stages of completion and available for industry and academic collaboration.

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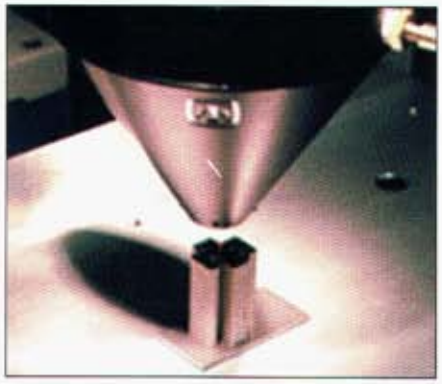
Precision Metallization Lab

Description

The Precision Metallization Laboratory (PML) is designed for characterizing, modeling, and deploying high-energy, automated manufacturing processes such as welding, plasma spray, laser cutting, heat treating, and ablation. The goal is to find ways to streamline manufacturing processes, accelerate the production cycle, and to monitor and make immediate adjustments to these automated processes when necessary.

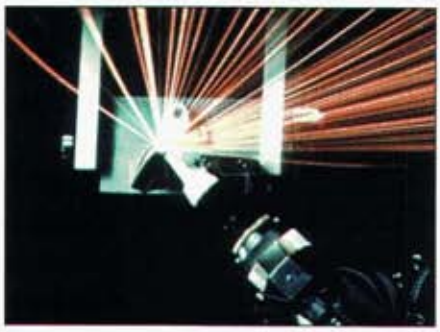
The PML integrates advanced manufacturing path-planning software developed at Sandia National Laboratories with sophisticated, real-time, sensor-based control. Path-planning software is used to optimize the efficiency of automated manufacturing processes by allowing the direct fabrication of components from computer-aided design based models, eliminating intermediate prototyping and testing steps and reducing the time required for programming robots.



Real-time, sensor-based control involves the use of sensors to feed information back to a computerized control center where necessary adjustments to processes are made instantly. The real-time sensor input can come from commonly available off-the-shelf units or custom sensors we design for highly specialized applications.

For the Department of Energy, the PML is aiding in the design and production of highly reliable containers for the safe and secure transport and storage of nuclear materials. Using robotic delivery systems, sensor and model-based control of joining processes is being developed to improve the quality of container production.

Features

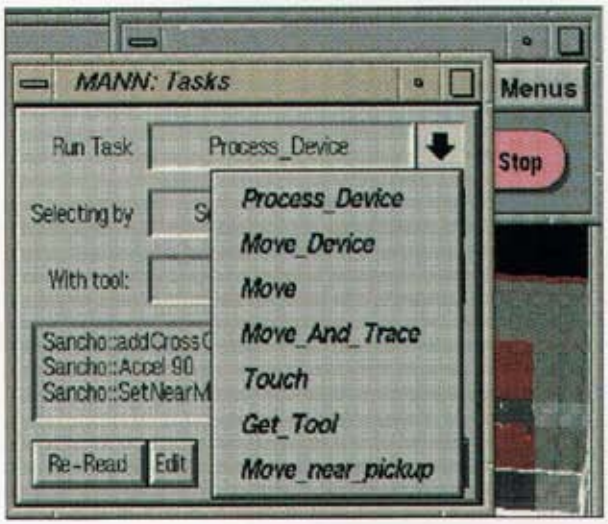


- **Precision, six-degree-of-freedom gantry robot with 9-foot by 11-foot by 6-foot work volume**
- **Tungsten and inert gas welding equipment**
- **High-power laser welding equipment**
- **Laser cutting devices**
- **Laser Engineered Net Shape (LENS) module for direct manufacturing without prototyping**
- **Automated, model-based motion planning**
- **Sensor-based control**

Collaboration

The Precision Metallization Laboratory is available for collaborative use. It can be used for a comprehensive R&D effort and to answer such questions as:

- **Is a new technological approach feasible?**
- **What fabrication capabilities must be communicated to designers to enable better product or process design?**
- **What will make the process better, safer, faster, or cheaper?**
- **What will it take to streamline the fabrication process for maximum efficiency and economy?**



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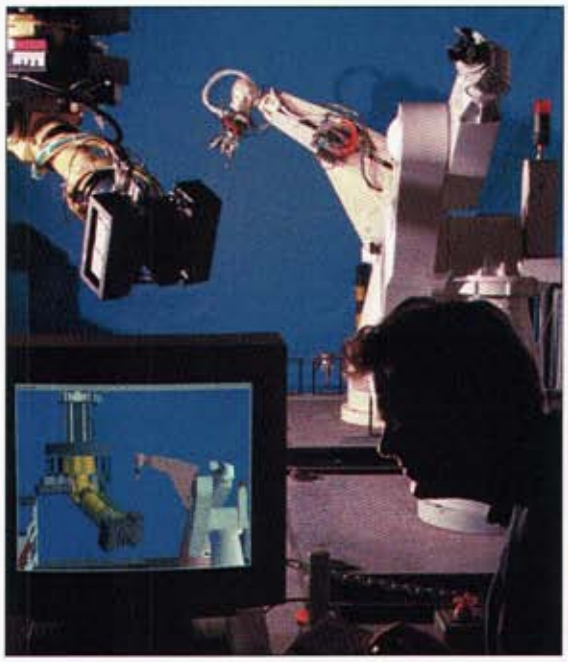
Intelligent Systems & Robotics Center

Fact Sheet

MegaLab



Description

MegaLab is a multipurpose facility designed for two distinct types of R&D efforts. MegaLab supports projects requiring the development and testing of a complete manufacturing process line. It also is equipped for R&D on processes involving large (tens of feet) or heavy (hundreds of pounds) pieces of equipment.

By providing a means for prototyping and testing such processes, MegaLab reduces the risk associated with the introduction of new process systems to the manufacturing floor. The facility is rapidly and inexpensively reconfigurable between projects of widely varying applications such as an integrated group of unit process cells, advanced material handling, or manipulation of large or heavy objects. MegaLab researchers, for example, have developed and refined coordinated robot control for complex assembly applications that involve movements beyond the capabilities of most industrial robots.

MegaLab is also developing software tools for something we call "virtual manufacturing." Virtual manufacturing goes beyond current concepts of integrated product and process design by providing models and simulations of production facilities to product designers to ensure cost-effective manufacturability.

MegaLab is also used for the development of "telerobotic" technologies. In a number of applications important to the Department of Energy, such as the cleanup of environmentally contaminated sites, human operators and intelligent machines must cooperate. This is telerobotics – automation of some remote operations, direct human control of the robot in others.

Features

- A precision gantry system equipped with machining tools for soft materials such as aluminum, plasma arc cutting, and accurate pick-and-place capabilities for assembly
- A high-payload gantry system capable of lifting objects up to 1,500 pounds
- Two high-payload pedestal robots to perform manipulation tasks, such as assembly, and processing, such as welding or painting
- One medium-payload pedestal robot for controls development
- Real-time sensor and model-based control of all robots in the lab
- Advanced controls software permitting cooperating action among any group of robots in the lab
- Pedestal robots mounted on specially designed movable platforms for rapid reconfiguration
- Powerful communications and programming interfaces for rapid system prototyping
- Quick-change tool adapters that allow robots to automatically change grippers or other tools
- Auxiliary hoist for 4,000-pound payload lift
- Common software platforms for rapid reconfiguration.
- Virtual collaborative control interfaces, which allow programming and remote control of the MegaLab robots from any location
- Multi-capability manufacturing lab for rapid prototyping of parts

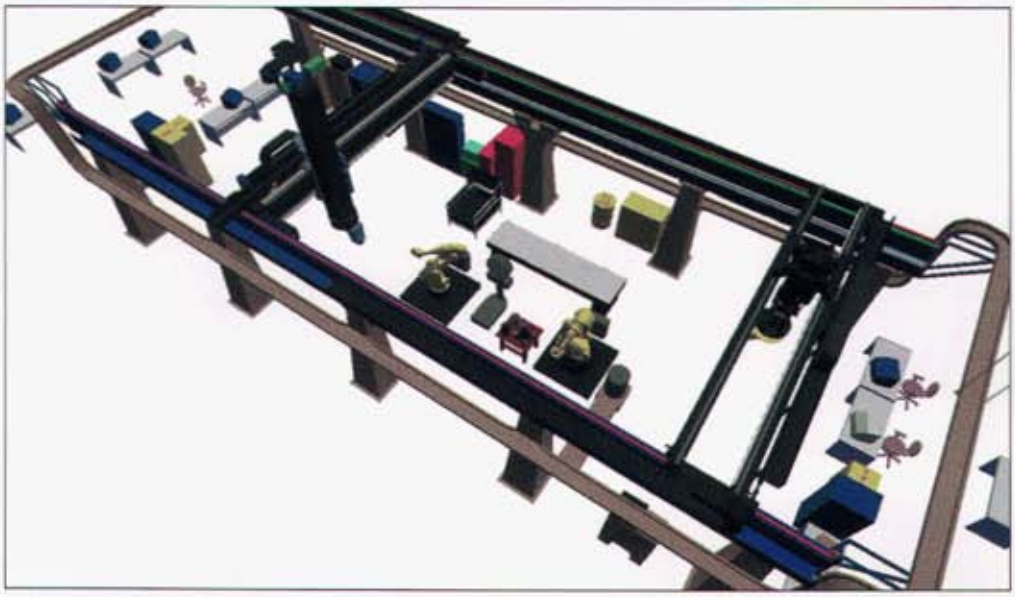
Collaboration

The MegaLab is available for collaborative use on the R&D problems of the manufacturing or service industries. MegaLab can be used for a comprehensive R&D effort, to solve one part of a manufacturing problem, or can provide subcontractual services as part of a larger team. MegaLab can be used to answer such questions as:

- Is a new technological approach feasible?
- What fabrication capabilities must be communicated to product designers to enable better product or process design?
- What system capabilities must be communicated to users or designers of a service facility to enable better productivity?
- What will make the process better, safer, faster, or cheaper?
- What will it take to streamline the process for maximum efficiency and economy?

Collaborators can develop:

- Agile process and tooling technologies
- Agile architectures
- Virtual manufacturing technologies
- Virtual facilities



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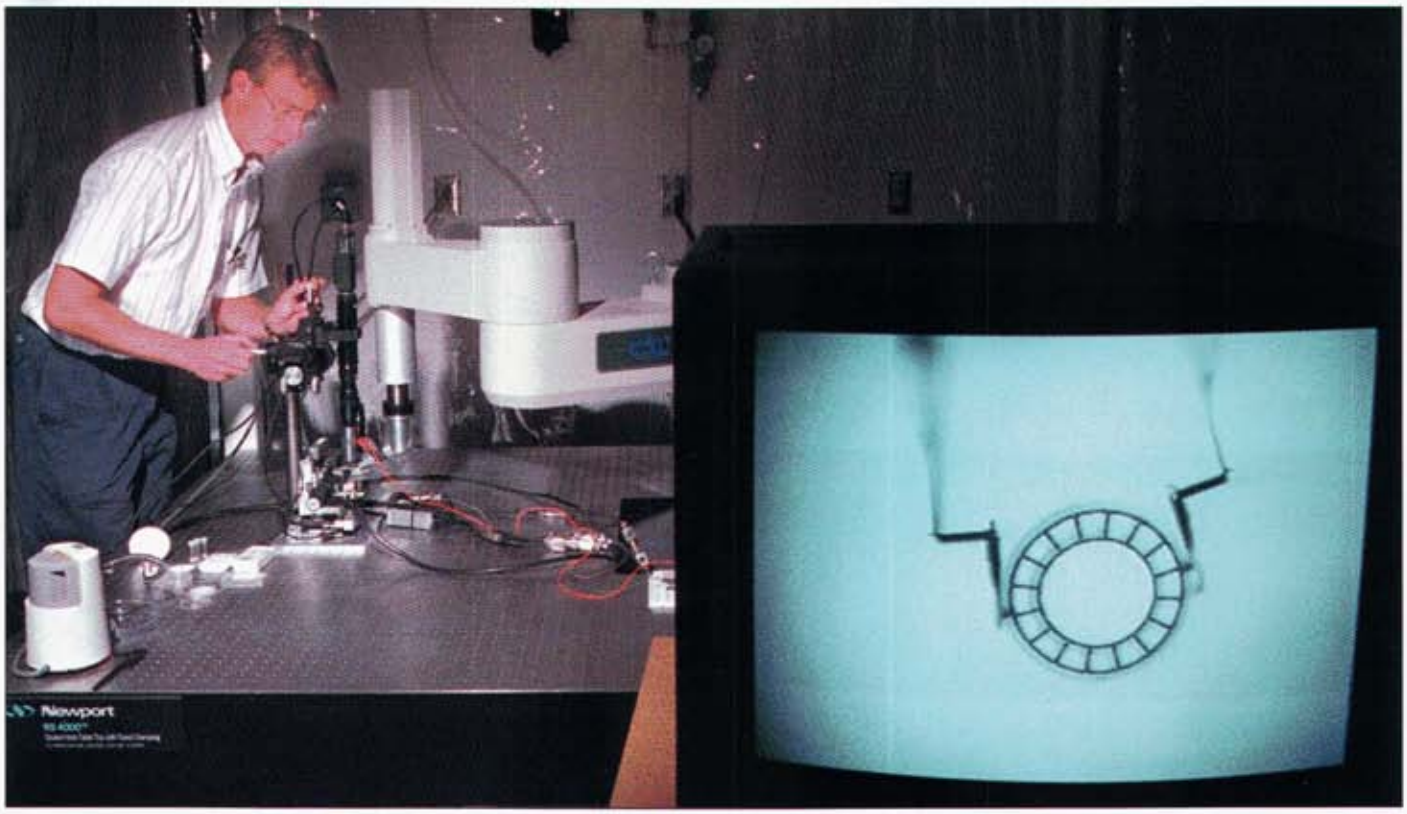
Intelligent Systems & Robotics Center

Fact Sheet

MicroManipulation Lab



Description

Microscopic machines are the focus of the MicroManipulation Laboratory. Created to investigate the automated assembly of microelectromechanical systems (MEMS) components, the laboratory is developing technologies for a robotic workcell that can assemble MEMS parts 10 to 100 microns in size—about the diameter of a human hair—into tiny machines for use in weapons components, surveillance devices, and microsurgery.

Currently, one of the major limiting factors in micromachine technology is the assembly process. Manual assembly is prohibitively expensive, and the required precision, operator stress, and eye strain associated with assembling such minute parts under a microscope make it impractical. The MicroManipulation Lab will develop technologies that will make such assembly easier and more cost-effective, thereby enabling practical applications for micromachines.

Sandia National Laboratories is currently investigating two methods of producing micromachine parts. The first is a surface machining technique similar to the way integrated circuits are developed. In surface machining, a silicon layer is built up on a substrate, and selected parts of the layer are etched away by a photolithographic process.

The process is repeated until a finished component—a microscopic spring, rotor, gear, diaphragm, or other mechanism—is produced. The advantage of surface machining is that all parts are fully assembled during fabrication.

The second method of forming parts is called LIGA (Lithography Galvanoforming Abforming). This method uses a silicon substrate as a mold in which electroplated parts are formed. Although making metal parts instead of silicon has advantages, one of the disadvantages is that LIGA parts must be assembled into a device after they are formed.

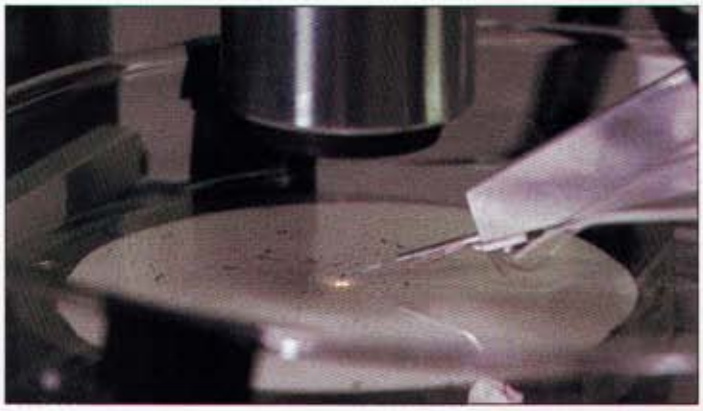
The MicroManipulation Laboratory is in the early stages of development. We are currently manipulating parts 100 microns in size using a teleoperated robotic system and recently used a pair of microtweezers to pick up and stack five polysilicon gears. We have developed preliminary image-processing routines that can automatically locate and guide the robotic system while assembling the parts.

Features

- **State-of-the-art motion control equipment including a robotic workcell with 40 nanometer positioning resolution**
- **Long-distance microscopes**
- **Real-time image processing equipment**
- **Laser interferometer equipment**
- **Microtweezers and actuators**
- **Portable class 100 clean room**
- **Automated precision agile assembly workcell**
- **Real-time computer vision to control servo mechanisms and motors for the alignment and assembly of parts with sub-micron tolerances**

Collaboration

In optoelectronics and optomechanics manufacturing, precision optical and mechanical assembly of increasingly small devices is a critical technology that will enable U.S. industrial competitiveness. The MicroManipulation Laboratory is available for collaborative research in such manufacturing applications as fiber optic alignment, integrated circuit assembly, and assembly of other computer-related devices. In addition to manufacturing, micromanipulation has potential applications in microbiology and microsurgery.



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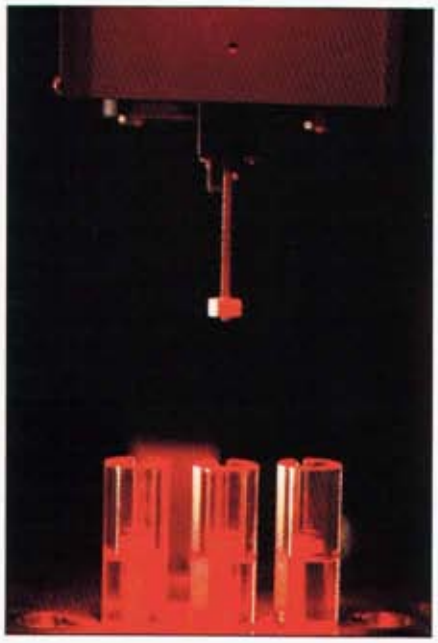
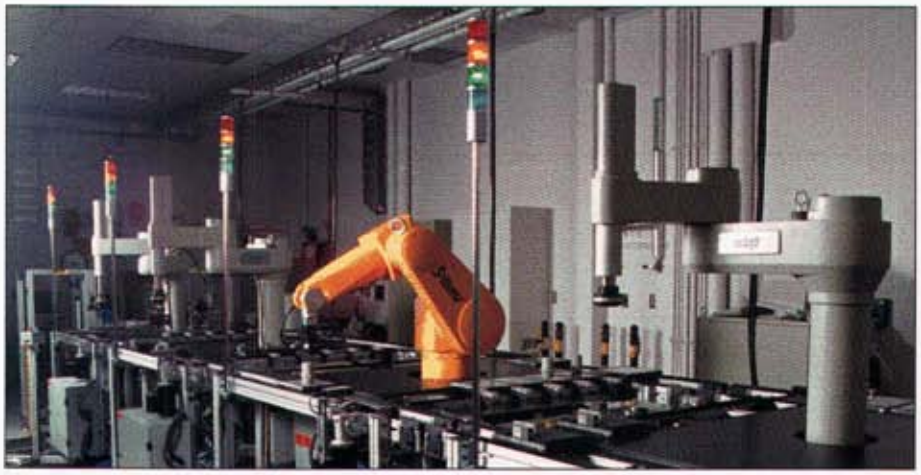
Intelligent Systems & Robotics Center

Fact Sheet

Agile Manufacturing Prototyping System



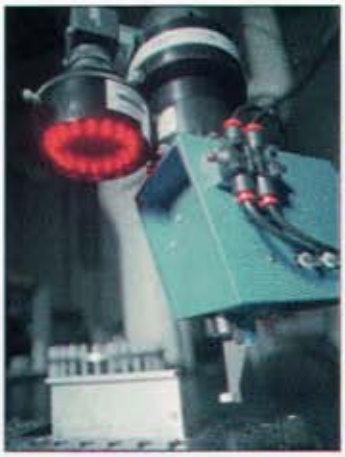


Description

In today's rapidly evolving marketplace, manufacturers must be able to quickly update and reconfigure production processes, hence the buzzword "agile" manufacturing. The Agile Manufacturing Prototyping System (AMPS) at Sandia National Laboratories is a unique resource that makes such responsiveness possible while reducing the risks associated with the traditional trial-and-error approach to introducing new processes or products into the manufacturing cycle.

AMPS is designed for the development and testing of agile production processes and their integration into existing manufacturing cycles. The facility brings together the most advanced manufacturing technologies and leading-edge automation technologies to create a resource for industry unlike any other in the country. As a national testbed, the AMPS facility provides an unparalleled opportunity for industrial users to test system-level concepts for flexible automation, for university researchers to test their ideas in an environment that more closely reflects the complexity of the factory floor, and for both to interact with one another to fully exploit complementary skills and needs.

AMPS consists of state-of-the-art flexible manufacturing hardware and software enhanced with Sandia advancements in sensor and model-based control; automated programming, assembly, and task planning; flexible fixturing; and automated reconfiguration technology.



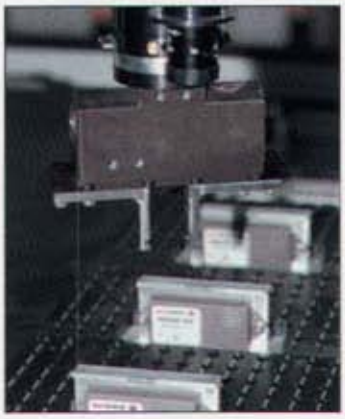
AMPS is also developing software tools for something we call "virtual manufacturing." Virtual manufacturing goes beyond current concepts of integrated product and process design by providing models and simulations of production processes to product designers to ensure cost-effective manufacturability.

In an era of declining defense spending, the Department of Energy (DOE)—like industry—needs exceptionally "agile" production facilities so that manufacturing is quickly responsive to change without time-consuming prototyping and retooling. Sandia and its DOE partners design and produce a vast range of mechanical, electronic, and electromechanical components and systems, ranging in size from the microscopic to those weighing several tons. AMPS focuses on agile production processes for electromechanical systems in the "bread box" size range.

Collaboration

AMPS is available for collaborative use. It can be used for a comprehensive R&D effort, to solve one part of a manufacturing problem, or it can provide subcontractual services as part of a larger team. AMPS can be used to answer such questions as:

- **Is a new technological approach feasible?**
- **What fabrication capabilities must be communicated to designers to enable better product or process design?**
- **Exactly what will make the process better, safer, faster, or cheaper?**
- **What will it take to streamline the fabrication process for maximum efficiency and economy?**



Collaborators can:

- **Develop agile process and tooling technologies**
- **Develop agile architectures**
- **Develop virtual manufacturing technologies.**

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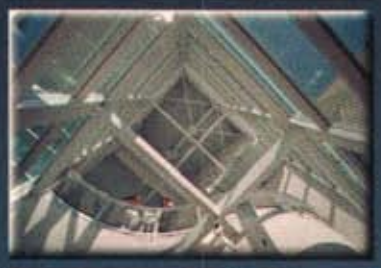

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