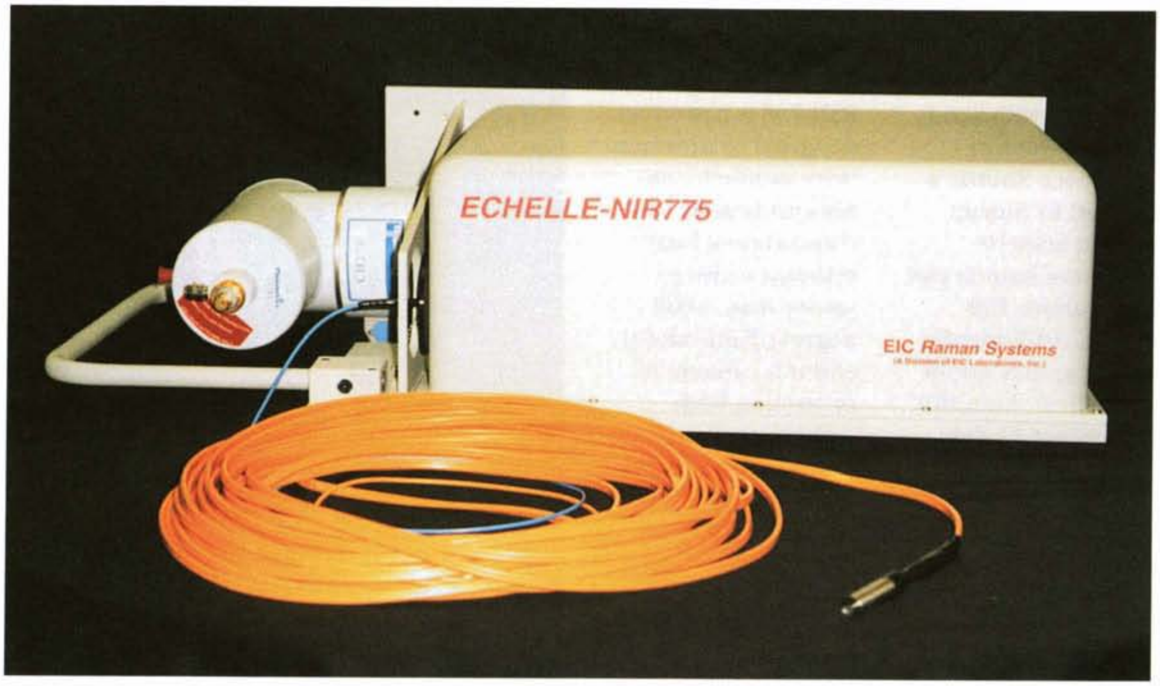
Small Business Innovations

In 1982, Congress established the Small Business Innovation Research (SBIR) program as a means of increasing opportunities for small businesses to participate in federal R&D activities. A related objective was to stimulate conversion of government-funded R&D into commercial applications; that benefits the U.S. economy—in terms of jobs created and contribution to the Gross Domestic Product—when the SBIR project generates a commercial spinoff.

Each technology generating agency of the government sets aside a percentage of its R&D budge for SBIR projects. There are 11 such agencies, each administering its own program independently under policy guidelines set by the Small Business Administration.



NASA's SBIR program has been eminently successful. It has provided the agency an additional source—beyond traditional aerospace firms—of R&D talent and innovative thought. Hundreds of new systems that advance NASA's capabilities for aerospace research and operations have emerged from the SBIR program. About one of every three SBIR projects results in a commercial spinoff.

EIC Fiber Optic Raman Spectrograph

E-TEK High Extinction Ratio Electro-optic Switch

Among representative examples of SBIR projects in the field of industrial productivity is a family of spectroscopic instruments developed by EIC Laboratories, Inc., Norwood, Massachusetts. EIC's instruments are based on Raman spectroscopy, a laser-based measurement technique that provides—through a unique vibrational spectrum—a molecular "fingerprint." Raman offers an advantage over infrared absorption techniques in its ability to function in aqueous environments. EIC is combining optical fiber technology with Raman methods to develop sensors that can be operated at a considerable distance from the laser excitation source and the spectrographic analysis instrumentation.

That technology was substantially advanced under a NASA SBIR contract designed to produce a Raman spectrograph with fiber optic sampling for such space applications as sensing hazardous fuel vapors, monitoring hydrogen gas, and making on-board rapid analyses of chemicals and minerals.

EIC successfully developed the NASA system then, using its own capital, refined the technology to create a commercially available Fiber Optic Raman Spectrograph and an associated patented RamanProbe™, a fiber optic probe that can make measurements up to 500 meters distant from the spectrograph. The system has no moving parts and is 10 times more compact than prior equipment.

Among industrial applications of the system are process control, polymer processing, analyzing liquid mixtures, corrosion analyses, monitoring hazardous materials, quality assurance assessments, and use in the manufacture of pharmaceuticals and semiconductors. The Raman spectrograph and probe system has been a singularly successful technology transfer, one that brought EIC $3 million in sales over a two-year period and resulted in creation of a new company division—EIC Raman Systems—to provide commercial Raman instruments and services.

Another example of a successfully commercialized NASA SBIR project is the work of E-TEK Dynamics, Inc., San Jose, California. Founded in 1983, E-TEK initially confined its activities to R&D in the fiber optic, microwave/millennium wave, and integrated opto-electronics disciplines. Since 1990, however, the company has been manufacturing and marketing a line of integrated optic and fiber optic components and instruments; annual sales grew from $2 million to $32 million in the 1990s and employment increased about tenfold.

E-TEK has worked on a number of NASA SBIRs. One of them, sponsored by Kennedy Space Center (KSC), called for a new line of electro-optic switches for fiber optic communications and optical signal processing applications. KSC wanted faster switch speeds, substantially smaller switches and much improved temperature stability.

Under the SBIR, E-TEK developed a line of microfabricated switches with nanosecond speed, extremely low crosstalk and the requisite temperature stability. The technology developed in the KSC project was integrated in E-TEK's commercial product line, specifically in a High Extinction Ratio Electro-optic Switch for high speed communications and optical signal processing, a 4x4 Switch Module, and a Programmable Fiberoptic Switch for routing optical signals, automatic optical testing and fiber optic communications.

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™RamanProbe is a trademark of EIC Laboratories, Inc.

E-TEK Programmable Fiberoptic Switch

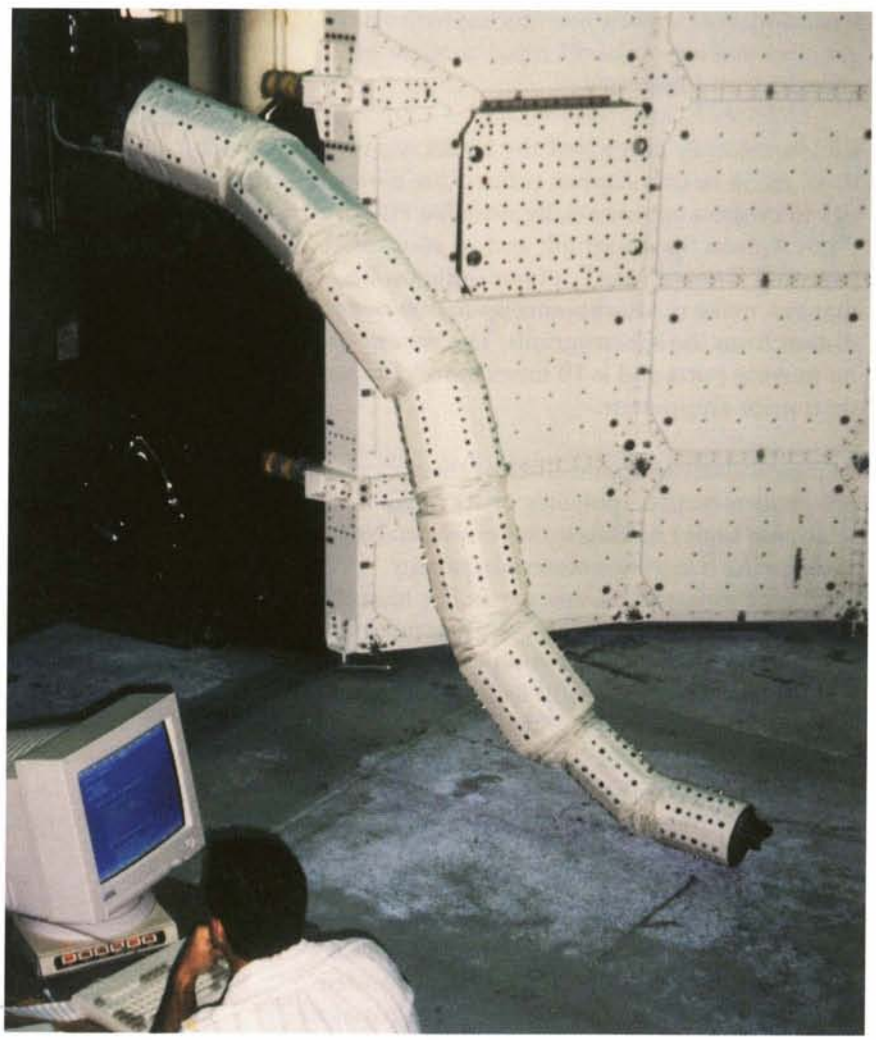
Small Business Innovations *Continued*

Before each Space Shuttle flight, an extraordinary amount of ground processing is required to assure safe and effective operation of the Shuttle and its payloads. To shave the time, lower the costs and increase the efficiency of these ground processing operations, NASA has turned increasingly to automated systems. But robotic systems pose problems, too; there is the chance that an errant robot might damage critical flight hardware.

Kennedy Space Center (KSC) saw a need for an obstacle detection system to insure that robots avoid collisions in their workplace. Accordingly, KSC sponsored a Small Business Innovation Research (SBIR) program with Merritt Systems, Inc. (MSI), Merritt Island, Florida, a research and consulting firm with special expertise in whole-arm proximity sensing technology for dextrous robot manipulators. From 1991 to 1995, KSC and MSI worked together on four SBIR projects to develop sensing and control technology for whole-arm robot manipulators.

From this work, Merritt Systems has developed a unique sensing architecture that allows retrofitting existing types of robots with a whole-arm obstacle detection and avoidance system that offers applications for NASA, other government agencies and their contractors, and also has broad potential for commercial use in such areas as robotic manufacturing systems, remote hazardous waste cleanup, and high value robotic tasks in constrained environments.

The key elements of the MSI system are the innovative sensorSkin and its associated compact, low cost smartSensor modules. Made



Merritt Systems' Tom Pigoski monitors the MSI Obstacle Detection System as it directs a robot arm away from an obstacle.

of flexible material, the sensorSkin can be cut and shaped to fit the mechanical arm of a robot. Within the skin is a distributed array of sensors—more than 1,000 of them, including proximity, motion, contact/force and temperature sensors—networked interchangeably over a single four-conductor wire. Each compact module contains on-board intelligence to perform all the analog processing and handle all communications between the module and the control computer. An on-board microcontroller processes the sensor information and transmits only relevant information back to the control computer.

MSI also developed a control algorithm for active collision avoidance during robot arm motions; as obstacles are encountered, a manipulator arm will react to avoid the obstacle while at the same time maintaining its desired end-effector position and orientation. The algorithm is incorporated in MSI's Robot Simulation and Control Environment (RSCE), which also provides kinematic control and three-dimensional graphic animation of robotic devices. The RSCE is designed as a tool for robotics training, analysis, design and control applications.

Robots incorporating the MSI sensorSkin and smartSensor technology are now being used in Space Shuttle processing. MSI proceeded to commercialize the technology; the initial commercial systems were delivered in 1995. MSI is investigating new applications in a variety of fields, including industrial process monitoring, building security, medical instrumentation and intelligent automation applications.

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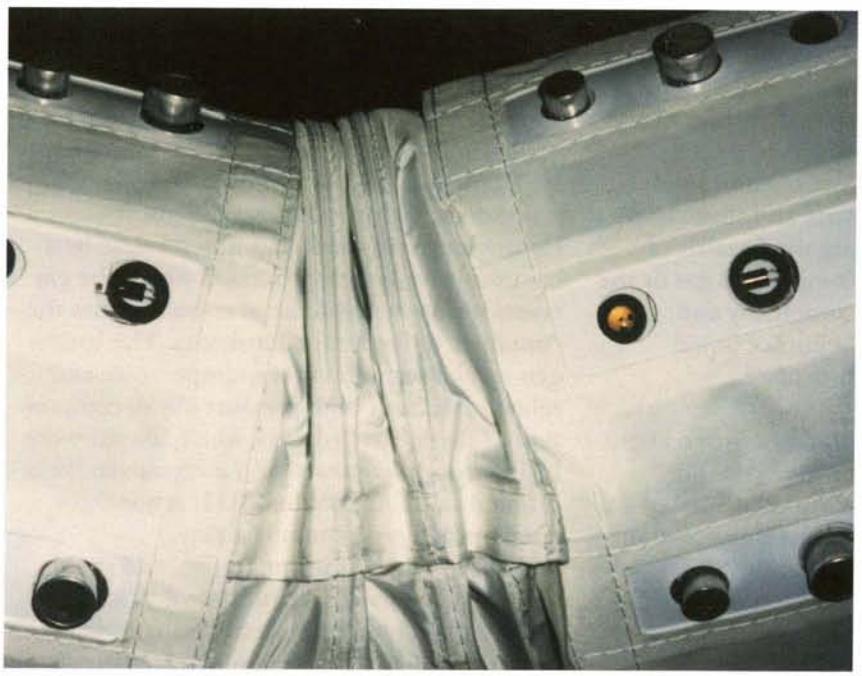


A closeup of the sensorSkin, which can contain more than 1,000 compact smartSensors providing intelligence to a control computer.

An operator adjusts the Obstacle Detection System in a robot arm.

Small Business Innovations *Continued*

Metal hydrides are chemical compounds formed by the reaction of hydrogen with metals, alloys or intermetallic compounds. Metal hydrides that react at room temperature were discovered in the 1960s. Even before that they had found many practical applications, for example, in processing steel, coating and bonding processes, in the preparation of metal powders, and in portable hydrogen generators for weather balloons.

Hydrogen Consultants, Inc. developed a compact metal hydride container for extended storage of industrial-use hydrogen.

Among the properties of metal hydrides is their ability to store hydrogen in a solid state, an area that has not been widely exploited. Since hydrogen is a common spacecraft propellant, but difficult to store, NASA was interested in the potential of metal hydrides as a means of storing hydrogen in solid state and thus avoiding the hazards of compressed gas or the complexity and boiloff of liquid hydrogen.

Marshall Space Flight Center (MSFC) awarded a Small Business Innovation Research (SBIR) contract to Hydrogen Consultants, Inc. (HCI), Littleton, Colorado to explore the utility of metal hydrides in spacecraft hydrogen systems. A follow-on Phase II SBIR directed HCI to design and develop two prototype hydride systems identified as promising in the Phase I effort: a Long Term Hydrogen Storage System for space use and a Metal Hydride Refrigerator for possible use aboard the International Space Station.

HCI delivered prototype systems to MSFC for testing. The Metal Hydride Refrigerator is thermally powered and can operate off a low to moderate source of waste heat, which makes it ideal for spacecraft applications where electric power carries a big weight penalty. Clearly, the refrigerator also has broad potential for Earth applications in view of the fact that it requires no compressor, a significant advantage in light of the planned phaseout of terrestrial freon-based refrigeration systems.

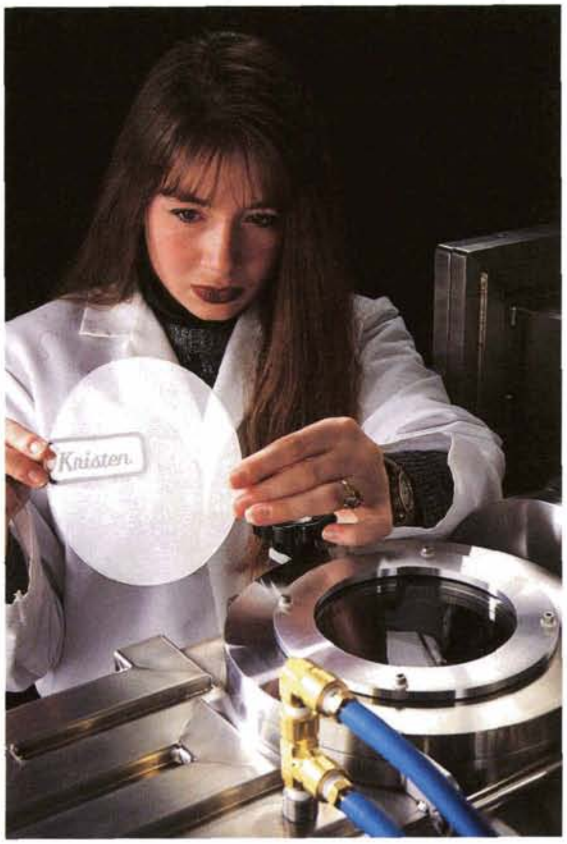
The Long Term Hydrogen Storage System delivered to MSFC enables storage of 10 pounds of hydrogen in a vessel only 15 inches in diameter and 32 inches long; its principal advantages are extended storage time and its compactness, compared with conventional cryogenic (very low temperature) storage. HCI has drawn upon its SBIR work to produce a commercial derivative of the technology under the trade name SOLID-H.

SOLID-H systems are a series of compact containers in which hydrogen is stored in solid state, offering an attractive alternative to large high-pressure cylinders and small disposable cylinders in industrial storage applications. Hydrogen gas is converted to solid state by a chemical absorption process in which the gas reacts with powdered metal crystals within the container to form metal hydrides. The hydrogen can be stored at room temperature and released without high pressures by decomposition of the metal hydrides, which liberates the hydrogen while returning the crystals to their original state. Among SOLID-H advantages cited by HCI are economy, safety, rechargeability of the containers, and their compactness; the containers are 9 ½ inches high, 6 to 6 ½ inches wide at the base, weigh only 4 ½ to 9 pounds, and have capacities from 40 to 140 liters.

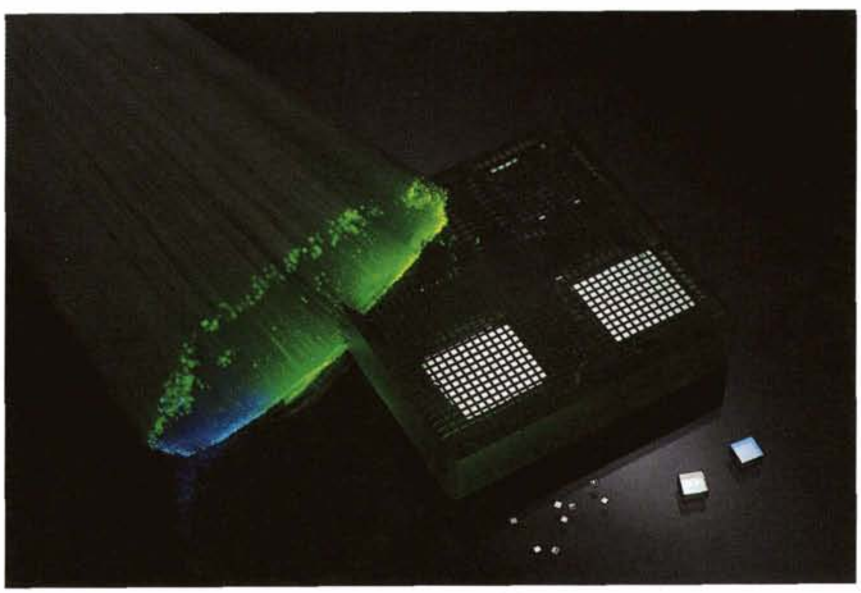
Another example of a NASA SBIR project that spawned commercial products is the work of Barr Associates, Inc., Westford, Massachusetts. Established in 1971, Barr has been a supplier of optical filters to NASA, the European Space Agency, and other space-oriented organizations since the company's inception. Barr has provided filters for instruments used in such NASA projects as the Hubble Space Telescope, the Galileo spacecraft, the Cassini planetary explorer to be launched in 1997, and the Multiple-angle Imaging Spectroradiometer slated for space service in 1998. The company's filters have flown on, or are scheduled to fly on, more than 40 space-based instruments.

In 1989, Barr was awarded an SBIR contract by Jet Propulsion Laboratory (JPL) to develop and fabricate advanced technology, image quality, space-qualified ultraviolet (UV) interference filters. UV filters are thin film-coated windows that act like sunglasses on instruments to enhance scientific observations, such as ozone studies, planetary atmospheric compositions, or the chemical reactions of environmental pollutants. Over a two-year period, Barr developed an advanced ion-assisted deposition process, which enabled creation of filters that eliminated certain technical problems associated with earlier filters and also broadened the range of environments in which the filters can be used.

Barr has since refined the JPL deposition technology and used it in a commercial line of filters that have utility in such applications as fiber optic communications, hand-held spectrometers, tabletop laboratory analyzers and a variety of industrial applications. The filters are stable, durable, provide high spectral performance, and can be fabricated in miniature sizes for portable instruments.



A Barr Associates technician unloads a filter from a chamber where thin film coatings are applied to ultraviolet filters.



Barr developed an advanced ion-assisted physical vapor deposition process to produce high performance filters for fiber optic communications and other applications.