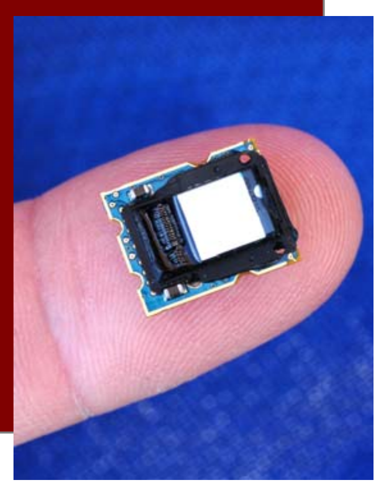
Technologies for Advanced Imaging Systems:

A Historical Review of ATP Funded Innovation

A New Generation of
Imaging Technologies

September, 2007



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"To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life."
-- The NIST Mission

Introduction

Images, including still and video images, are pervasive in our world. In healthcare, a wide variety of imaging technologies enable early diagnosis and precise treatment including x-rays, ultrasound, and MRI. In manufacturing, new uses for imaging technology have emerged to improve all phases of the manufacturing process from design to quality control. In homeland security, biometrics, surveillance, and access control applications use new imaging technologies to address security challenges.

Since 1991, the Advanced Technology Program's (ATP) investments in innovative technologies for advanced imaging systems have enabled the development of new technologies with applications in these areas and many more. These advancements enable businesses and individuals to use image data more easily and at lower cost, and responded to a broad range of societal needs.

This report examines the innovative research and development (R&D) for advanced imaging that was funded by ATP between 1991 and 2004 including both component technologies and complete systems. These include technologies for the capture, processing, transmission, and/or presentation of two-dimensional (2D) and/or three-dimensional (3D) images, as well as the integration of those technologies into complete systems. Images can be created by using electromagnetic (e.g., x-ray, infrared, or visible light), sound (e.g., ultrasound), or synthetic sources (e.g., virtual reality). The purpose of an imaging system is to provide information directly to end users or to another information system (e.g., manufacturing inspection equipment automatically looking for defects).

Investments in Technologies for Imaging Systems

Between 1991 and 2004, ATP awarded **78 projects** representing approximately **$430.4 million** of industrial R&D spending on technologies that directly impacted advanced imaging systems. **Table 1** provides an overall summary of the Federal and industry funding and the composition of the awards.

Table 1: Summary of Project Composition and Funding for Advanced Imaging Systems[1]

Total R&D Funding (in millions)	**$430.4**		**Total Recipients (Project Leads and Joint Venture Partners)**	**121**
ATP Share (in millions)	$234.0		Small Companies	71
Industry Share (in millions)	$196.2		Medium Companies	24
			Large Companies	23
Total Awards	**78**		Universities	1
Single Applicants	61		Non-Profits	2
Joint Ventures	17			
Single Applicants by Lead	**61**		**Joint Venture Leads**	**17**
Small Company	52		Small Company	5
Medium Company	6		Medium Company	9
Large Company	3		Large Company	3

1 Company size is defined as follows: a *large* company is on the Fortune 500 list (or has equivalent revenues) at the time of proposal submission; a *small* company has less than 500 employees; and a *medium* size company has more than 500 employees but is not on the Fortune 500 list.

Companies of all sizes and from 18 states and the District of Columbia have led projects in advanced imaging. As can be seen from Table 1, 95 recipients (project leads or joint venture partners) or almost 78% of the total recipients have been small or medium-sized companies. This participation is significant because of the substantial contribution that small and medium companies make to new technology development in the United States. [2]

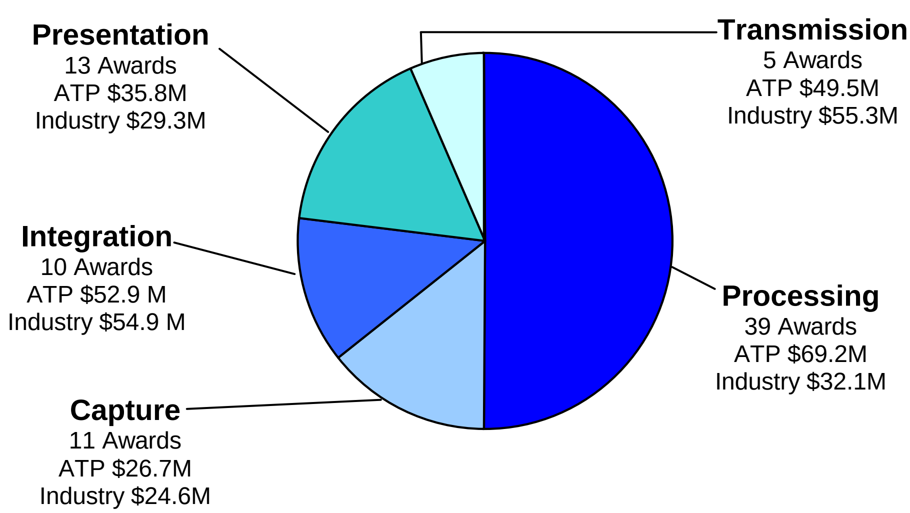
What Advanced Imaging Systems Technologies Were Funded?

Advanced imaging systems projects have focused on all of the major areas of imaging – capture, processing, transmission and presentation – either as single component technologies or as integrated systems. Specific definitions for each of these technical areas follow:

- *Image Capture* - technologies that generate two-dimensional (2D) and/or three-dimensional (3D) spatial images, including the component technologies required to make a complete system to capture the image, such as sources, lenses, etc.
- *Image Processing* – technologies that index, transform, analyze or extract information from, or insert information into two-dimensional (2D) and/or three-dimensional (3D) image or video data including data from virtual reality systems.
- *Image Transmission* – technologies that address the specific needs of transferring image data (including video data) over distances. General purpose networking technologies are not included.
- *Image Presentation* – technologies that enable the presentation of image data, such as displays, primarily designed to meet the needs of non-text based presentation of information.
- *System Integration* – systems that combine multiple innovations across multiple technical areas. For example, systems that combine innovation in the camera with innovative image processing techniques.

Figure 1 provides more detailed information about investments in the technical areas discussed above.

Figure 1: Advanced Imaging Projects by Technical Area



[2] Small Business Administration report - http://www.sba.gov/advo/research/rs225tot.pdf

Imaging Systems Enable Diverse Applications Addressing National Needs

Imaging technology is pervasive and critical to numerous application areas and industrial use and societal challenges. This includes the following early-on applications for the funded projects:

- **Healthcare -** Imaging is fundamental to medical diagnosis and treatment in the 21st century especially new image capture and image analysis technologies. As one recent technology roadmap for healthcare states: "Medical imaging technology has enormous potential to contribute to the improvement of health care in this new century and will, no doubt, have the power to contribute to solving some of the financial pressures which also beset health care."[3]
- **Homeland Security** – Imaging is fundamental to new access control and surveillance systems using innovative biometrics, three-dimensional facial modeling, and image analysis techniques. The Department of Homeland Security "is also harnessing 21st century technology and biometric information to increase the likelihood of apprehending criminal or terrorist elements attempting to enter the U.S. … Biometrics identify the traveler, protect privacy and make it virtually impossible to cross borders using fraudulent documents or to assume another's identity."[4]
- **Manufacturing** – New imaging technologies are enabling new manufacturing applications in automated quality inspection to reduce costly defects during manufacturing and new techniques for recognizing and modeling parts from initial design to production. These technologies can be directly relevant to the manufacturing process or indirectly support process improvement and impact manufacturing sectors ranging from cutting edge semiconductor manufacturing to traditional steel mills.
- **Multi-use applications -** Applications of imaging technology are pervasive in today's economy. These projects intended to develop tools and devices for creating, managing, editing, distributing and displaying digital content for a wide range of industries rather than being specifically tailored for the needs of one industry segment. For example, new display technologies making higher quality video display more accurate and affordable for medical, industrial, or educational uses.
- **Specialized applications -** New uses of imaging technology are constantly emerging: For example, projects that automate analysis of seismic data (a three dimensional image) to identify oil deposits, and that use specialized techniques for determining missing image content in digitized versions of damaged film.

Benefits of these technologies will spillover from the initial users and industries as "spillover" benefits to the nation as a result of new capabilities being incorporated in new products and services.

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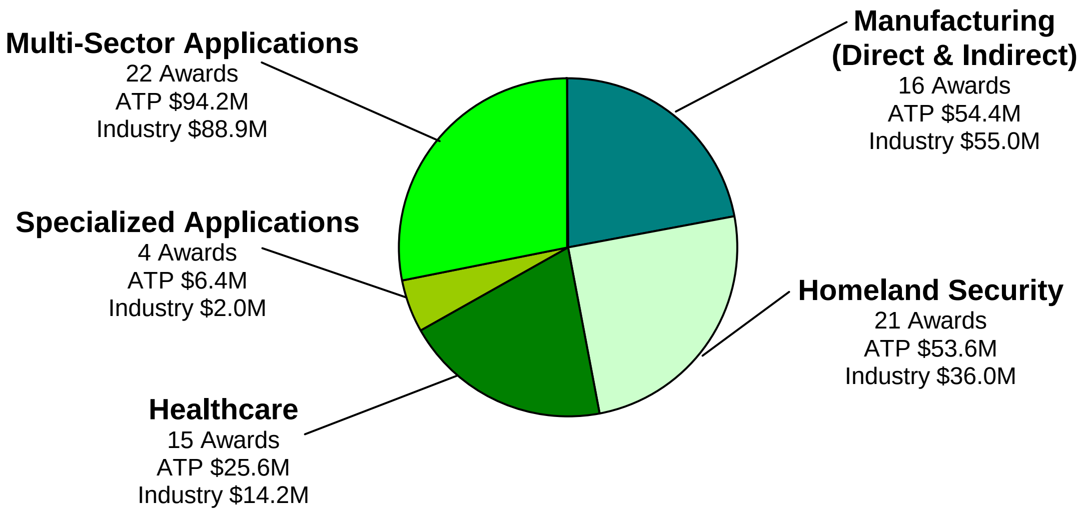
3 *Future Needs for Medical Imaging in Health Care.* Report of Working Group 1 Medical Imaging Technology Roadmap, Industry Canada, 2000 p. 15 http://strategis.ic.gc.ca/epic/internet/inmitr-crtim.nsf/en/h_hm00038e.html

4 Department of Homeland Security website http://www.dhs.gov/xnews/releases/pr_1158347347660.shtm

Figure 2 presents a summary of the early applications of advanced imaging system technologies.

Figure 2: Imaging Awards by Early Application Area



The following sections present a further analysis of each of the five technical areas, as well as examples of funded projects within each area.[5] **Appendix A** lists all 78 awards grouped within the five technical areas. **Appendix B** lists additional references on specific ATP funded advanced imaging systems projects not otherwise discussed in this report.

Image Capture

Eleven (11) image capture awards were funded representing approximately **$51.3 million** total R&D spending. Specific technologies include the development of specialized imaging sources (e.g, x-ray, laser), lenses, receivers, and complete capture systems, such as cameras or medical imaging scanners (e.g., MRI systems). Applications include medical diagnosis, homeland security especially facilities security and biometrics, and specialized manufacturing such as lithography.

Low-Cost, Low Light Level Video Camera

Intevac's NightVista E2010 low light level camera. Picture courtesy of Intevac.

Intevac (Santa Clara, CA) and **National Semiconductor Corporation** (Santa Clara, CA) were awarded $5.3 million over two and a half years in September, 1999 to develop new sensors and an automated manufacturing process to enable the production of low-cost, high-performance low-light-level (LLL) cameras.[6]

In the late 1990s, LLL cameras, derived from military research, cost as much as $10,000 each - too expensive for most commercial applications. To reduce the cost of such cameras, significant breakthroughs were needed in both electronics and in manufacturing technologies. Intevac proposed to develop three critical innovations: making a new microchip; incorporating the

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[5] A listing of all the projects can be found in Appendix A. Additional sources of information on all the projects discussed can be found in Appendix B.

[6] Project-Brief: http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=99-01-2017

microchip with the camera's image intensifier; and creating the automated manufacturing equipment for assembling the camera.

The project used conventional CMOS[7] chip technology, then in use to make most low-cost computer chips, to fabricate a microchip with the necessary camera and sensor electronics onboard. Creating a CMOS sensor that detected low intensity infrared light as well as visible light so that the same system could be used under a wide range of lighting conditions, was a significant technical challenge. Another challenge was in the packaging of the camera and sensor components using low cost CMOS architecture, stretching the state of the art for infrared sensors in this technology. The chip was then combined with an image intensifier to create the new LLL camera. Because CMOS technology is relatively inexpensive, the new cameras are inherently less costly. However, only with the successful innovations in the automated assembly processes were final cameras commercially possible.

Unlike prior LLL cameras which work well only in darkness, the new cameras, known as the Intevac NightVista™ system, worked just as well in all types of lighting conditions, including bright daylight. The camera could revolutionize industrial and home security systems, as well as law enforcement applications. According to National Semiconductor Corporation, "the compact design makes this unit attractive for concealed installations, portable uses, or legacy systems with limited space. Additionally, the camera's very low power draw facilitates its use in remote areas where power is at a premium."

Low-Cost Amorphous Silicon Manufacturing for Digital Mammography and Other Uses

GE Research (Schenectady, NY) and **PerkinElmer Optoelectronics** (Santa Clara, CA) were awarded $1.6 million over 5 years in September, 1995 to develop an improved, low-cost, high-yield manufacturing process for fabricating large amorphous silicon devices for use in medical imaging systems and other applications.[8]

Prior to this project, the amorphous silicon detectors used in digital medical imaging systems were expensive to produce due to the high cost of making the amorphous silicon. By the mid-1990's, low cost amorphous silicon manufacturing technology was possible only in GE's laboratories, but not in large-scale manufacturing. This limited the technology to high end applications only, such as cardiac imaging.

General Electric's digital mammography unit, the Senographe 2000D. Courtesy of General Electric Company.

To reduce manufacturing costs and broaden the technology's uses, GE and Perkin Elmer successfully developed new manufacturing technologies that included: reducing the total number of process steps from 300 to 200; reducing the total number of mask steps, the critical manufacturing challenge, from 11 steps to 7; and reducing the total cost of the manufacturing process by 25%. GE also successfully transferred the manufacturing technology to Perkin Elmer. The reduction in cost of this component technology enabled new commercial digital image capture systems using this technology.

The medical applications of this technology have focused on digital mammography and digital radiography. The major benefits are superior breast cancer detection through lower false positives, fewer unnecessary

[7] Complementary Metal Oxide Semiconductor

[8] Project Brief: http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=95-01-0152
Gem: http://www.atp.nist.gov/gems/ge-95-01-0152.htm

biopsies, reduced radiation exposure, and reduced medical costs through enhanced clinical productivity. The potential economic impact of the digital mammography applications alone is substantial, estimated to be between $219 million and $339 million, with a benefit-to-cost range of 125:1 to 193:1.[9]

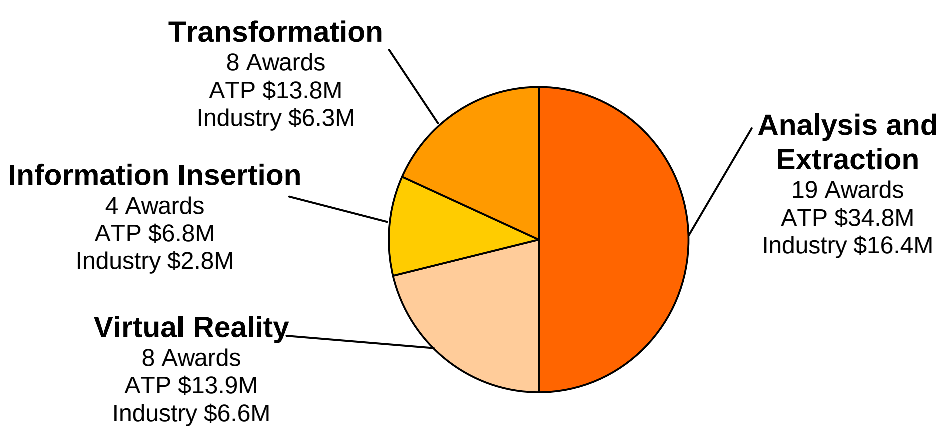
The enabling technology created even broader economic benefits. Perkin Elmer is pursuing sales of low-cost amorphous silicon detectors for uses in other industrial imaging applications such as printed circuit board inspection, pipeline inspection, bone densitometry, veterinary imaging, and airport and customs cargo inspection for homeland security.

Image Processing

Thirty-nine (39) image processing awards were funded representing approximately **$101.3 million** of total R&D spending. Specific technologies include a broad range of topics and application areas. Projects in image processing fall within the four technical categories shown below. **Figure 3** presents a breakdown of the image processing projects within these four categories.

- **Analysis and Extraction -** technologies that extract specific information about one or more features or objects in an image (e.g., automatic topic indexing of video, and isolating specific objects from background information). Applications include healthcare diagnosis and identification of faces in a crowd scene.
- **Information Insertion -** technologies that add new information to an existing image (e.g., adding a watermark or other signal to prevent unauthorized use of a movie). Applications include video piracy prevention or video editing.
- **Transformation -** technologies that fundamentally transform an entire image (e.g., compression). Applications include specialized security and surveillance systems and media restoration.
- **Virtual Reality -** technologies that create synthetic images from data (e.g., advanced animation technologies). Applications include training, simulation or entertainment.

Figure 3: Image Processing Technology Projects



9 Economic Study: http://www.atp.nist.gov/eao/gcr03-844/contents.htm

Adaptive Video Codec for Information Networks

cVideo[10] (originally Cubic Defense Systems) (San Diego, CA) was awarded $1.7 million over 2.5 years in September, 1995 to develop next-generation video compression technology to enable the delivery of multiple simultaneous streams of digital video to personal computers. [11]

A key technical barrier to the growth of the information industry in the mid-1990s was the limited capacity of existing networks, many of which could not carry large amounts of digital video. New technology was needed to increase network capacity while also reducing video transport costs. Universal access would be promoted if video could be delivered to personal computers, which were, in 1995, in use by more than 100 million people worldwide.

Cubic Defense Systems Inc. proposed to develop a prototype video compression technology that would compress color image and synchronized audio data to greater than 150:1. This improvement enabled the delivery of video to personal computers. Cubic Defense Systems also created a new division, Cubic Video Comm (later spun out as cVideo), to pursue this project.

Cubic Video Comm developed a new concept that offered superior compression to the then current technology. They wrote and tested algorithms and techniques that send high-quality images almost instantly to PCs, including those in remote locations. The technology overcame the problems of lost or corrupted data and long files overflowing limited buffers. After spinning out Cubic Video Comm as a new, separate company under the name cVideo in 1999, cVideo developed several commercial products using this technology. These products included a web video-streaming software package; a video electronic mail system; and a surveillance system, with many customized applications. About 7,500 facilities nationwide are using the surveillance technology, which can send images from 16 cameras to a single PC, with simultaneous playback and storage to a hard drive. The system improves upon videotape security system by offering better image quality, access to images, and archiving.

4ULock product.
Courtesy of cVideo.

Robust Extraction of 3D Models from Video Sequences

AliveTech (formerly Geometrix, Inc.) (San Jose, CA) was awarded $2.0 million over 3 years in November, 1999 to develop software that automatically creates 3D graphics databases by extracting 3D information from conventional video camcorder images dramatically lowering the cost of building 3D images and 3D models of objects.[12]

In the late 1990s, three dimensional (3D) images were very rare and expensive to capture and process. Geometrix proposed to develop software that would use conventional two dimensional digital video data to build highly accurate 3D models of objects. These models could be stored in graphics databases and easily manipulated thereby lowering the cost of using 3D models. Geometrix's plan was to automate image analysis and extraction of data from a series of two-dimensional images to create a highly accurate 3D model, even when the objects were in motion or partly occluded. Geometrix foresaw potential applications in construction, architecture, art, entertainment, forensics, military planning, industrial training and many other fields for this technology.

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[10] Acquired by SYS Technologies in 2006

[11] Project Brief: http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=95-04-0008

[12] Project Brief: http://jazz.nist.gov/atpcf/prjbriefs/prjbriefs.cfm?ProjectNumber=99-01-3012

The resulting technology has been commercialized in the security markets due to its accuracy in identifying facial features. The technology developed by Geometrix (later acquired by Alive Tech) creates a three dimensional facial image, a unique digital biometric, that can be quickly referenced to provide accurate biometric confirmation of identity in image recognition security systems.

Three dimensional models of faces constructed from video sequences. Courtesy of AliveTech, Inc.

The technology has been successfully deployed for prisoner processing at the Cobb County Adult Detention Facility in Atlanta, Georgia. The 3D database for the prison currently has over 90,000 inmates registered and has been operational since April 2004 with zero false releases. In another test, the TSA Testing Facility at the National Safe Skies Alliance indicated this was the only facial recognition system that they have been unable to "spoof".

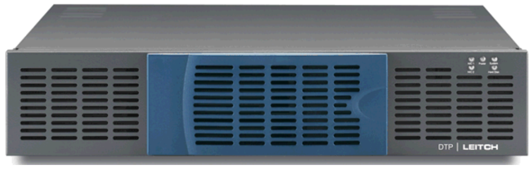
Dale Church, CEO of Alive Tech, says that “the Alive Tech system gives law enforcement officers an advanced tool in identifying inmates, which eliminates an inmate’s ability to use an alias and ensures that only the right prisoner is released. The 3-D Facial System interfaces with prison management systems and integrates with fingerprint identification, as well.”

Image Transmission

Five (5) image transmission awards were funded representing approximately **$104.8 million** of total R&D spending. Specific funded technologies included control systems for maximizing efficient video broadcasting over limited channels and hardware technology specifically tailored for video transmission. Example applications of these technologies include the residential reception of high definition digital television, or transmission of highly accurate medical images.

High Definition Television Broadcast Technology

Sarnoff Corporation (Princeton, NJ), **IBM Corp.** (Yorktown Heights, NY), **New Jersey Network** (Trenton, NJ), **Sun Microsystems** (Santa Clara, CA), **Thales Broadcast & Media** (Southwick, MA), **Thomson Consumer Electronics** (Indianapolis, IN), **NBC** (NY, NY), **MCI** (Richardson, TX), and **Wegener Communications, Inc.** (Duluth, GA) were awarded $28.4 million over 5 years in September, 1995 to develop new technologies for HDTV broadcasting, particularly a system for processing compressed High Definition Digital TV signals and solutions for more efficient operation of HDTV transmission.[13]



Digital Turnaround Processor. Courtesy of Harris, Inc.

When this project started in the fall of 1995, digital television and the transition from analog to digital television was in its infancy. Television stations which had used the same analog signal format since 1950 would now receive, edit, and broadcast up to 18 formats of digital signals (as was then under discussion). This Sarnoff led joint venture (JV) proposed to develop key technologies for television studios to use in receiving

13 Project Brief: http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=95-04-0026
Economic Study: http://www.atp.nist.gov/eao/gcr03-859/contents.htm

network transmissions, editing the digital content (for example, to add a station logo), and retransmitting the signal to their local audience. The JV developed a new studio system for editing compressed video content and new digital adaptive predistortion (DAP) technology to enable more efficient signal transmission and effective use of adjacent broadcast frequencies.

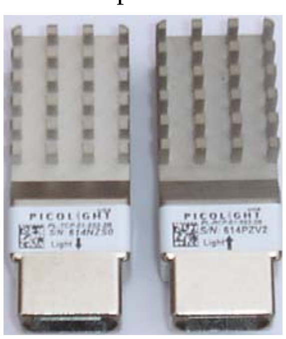
The resulting technologies were subsequently commercialized and have entered into service at television stations around the country helping to hasten the transition to digital television. AgileVision[14], a spin-off from Sarnoff and Mercury Computer Systems commercialized "compressed bit stream switching and server technologies" to the Public Broadcasting Service (PBS) community. This product is now called the Digital Turnaround Processor. Thales Broadcast & Media (previously named Thomcast) successfully commercialized the DAP transmitter technology. By 2003, ten Public Broadcasting Stations were using the Digital Turnaround Processor as the core of their conversion to digital television broadcasting.

In 2003, Thales Broadcast & Media won a prestigious Emmy award for technology excellence for the DAP transmitter technology. Agilevision, and its successor company Leitch, have also won several awards for the Digital Turnaround Processor.

Ultra-Compact Packaging Technology for Telemedicine, Telecommunications, and Next Generation I/O

Picolight, Inc. (Boulder, CO) was awarded, in November 1999, $2.0 million over 2.5 years to develop advanced packaging technologies and prototype cost-effective miniature fiber-optic datacom transceivers for use in desktop and laptop computers and other consumer products.[15]

The widespread use of very fast (multi-gigabit-per-second) digital connections for high-speed transmission of video images can be made possible by dramatic reductions in the price and size of fiber-optic transceivers, a combined transmitter and receiver component which uses microchip lasers for data transmission. In 1999, when Picolight proposed to develop the key technologies to make such a transmitter/receiver technology possible, the transceiver technology was too bulky and costly to be used in a wide range of consumer products, including desktop and laptop computers.



Transceiver. Courtesy of Picolight, Inc.

Picolight, Inc. developed an advanced packaging technology and a prototype miniature fiber-optic datacom transceiver which greatly reduced transceiver size and manufacturing cost, both by over a factor of 10. To achieve these goals, Picolight developed innovative optics and electronics to replace traditional housings; a new microchip platform for mounting electronic and optoelectronic devices; new processes for making high-quality micro-optics; and new automated testing procedures for the individual optoelectronic components and for the complete transceiver.

In 2003, Picolight demonstrated a small form-factor, pluggable transceiver incorporating a 1310-nm vertical cavity surface-emitting laser (VCSEL), based on its project results. This demonstration of 1310-nm VCSEL-based transceivers was a key industry milestone on the road to extending the benefits of enterprise optics to metropolitan-access and optical Ethernet applications in video and data transmission. The Picolight prototype transceiver was successfully demonstrated in a telemedicine network at the University of Alabama at Birmingham Medical Center, transmitting a variety of medical images over existing fiber cables at the Center. Picolight viewed this first test as an important stepping stone to entering broad-based commercial markets.

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14 AgileVision was aquired by Leitch which was subsequently acquired by Harris.

15 Project Brief: http://jazz.nist.gov/atpcf/prjbriefs.cfm?ProjectNumber=99-01-2029

Image Presentation

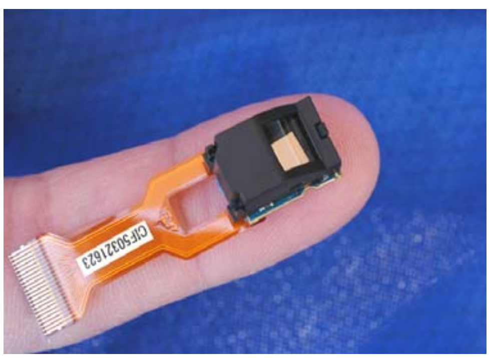
Thirteen (13) image presentation awards were funded representing approximately **$65.1 million** of total R&D spending. Specific technologies included image displays, screens, and image generators. Example applications of these technologies included medical high definition displays, residential projection technologies, and industrial 3D displays.

FLC/VLSI High-Definition Image Generators

Displaytech, Inc., (Longmont, CO) was awarded $1.7 million over 2 years in February, 1995 to develop a new image-generation technology for advanced display, printing, and computing applications. At the heart of the technology is a silicon microchip with circuitry densely patterned as a miniaturized high-resolution pixel array, coated with a layer of ferroelectric liquid crystal (FLC), which responds to an electrical signal in order to generate the grey scale image.[16]

In the early 1990s, the excessive size and cost, and the slow speed of existing liquid crystal displays (LCDs) hindered the development of convergent devices such as personal organizers, laptop computers, and portable phones that are integrated into a single unit. In the search for faster, smaller, cheaper, and better displays, researchers turned to a new type of liquid crystal - the ferroelectric liquid crystal (FLC). FLC displays are capable of full-color high resolution video display, but in the early 1990's they did not have other important attributes needed for commercial use such as longevity (the displays lasted only a few hundred hours before burning out).

In 1994, Displaytech could fabricate working FLC micro-displays, but it could only fabricate them one at a time. For these reasons, the company proposed to develop the technologies for large-scale manufacturing and increased device lifetime.



A Ferroelectric Liquid Crystal Display Chip. Courtesy of Displaytech, Inc.

During the project, two key issues were addressed: (i) developing a low-cost manufacturing process for wafer-scale mass production of silicon-based micro-displays, and (ii) making reliable FLC materials that work over a wide temperature range. Technical barriers were overcome to achieve a 600% increase in final image quality, 100% increase in product lifetime, and a decrease in per-unit costs from $6,000 to $160. As a result, production capacity at Displaytech increased from one micro-display at a time in 1994 to a capacity of over 1 million micro-displays per year by 2000.

The project has helped Displaytech attract over $80 million of private sector capital, from which a state-of-the-art pilot plant was built in Colorado. Its manufacturing partner, Miyota, built a $30 million factory in Japan for large-scale production of the Displaytech micro-displays for the Asian market. By 2004, the combined output of these U.S. and overseas factories was close to 4 million micro-displays per year. The technology has been integrated into JVC camcorder displays, and Hewlett-Packard, Concord, and Minolta electronic viewfinders, as well as more than 20 other consumer products from Kodak, Sony, Olympus, Hitachi, and Kyocera. Building on the success of its electronic viewfinder products, Displaytech plans future developments in the areas of pocket projectors, projection systems, head mounted displays, and holographic data storage.

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16 Project Brief: http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=94-01-0402
Gem: http://www.atp.nist.gov/gems/dt-94-01-0402.htm
Status Report: http://statusreports.atp.nist.gov/reports/94-01-0402.htm

Holographic Graded-Index Non-Lambertian Scattering Screens with Light-Shaping Capability

Physical Optics Corporation, (Torrance, CA) was awarded $0.8 million over 2 years in February, 1994 to develop a unique beam-shaping technology based on inexpensive holographic graded-index scattering screens to direct light from displays, light sources, projection screens, and other devices in desired directions without loss to the side or to back-scattering.[17]

Conventional light-diffusing screens, such as movie screens or the frosted glass used in laptop computer displays, send light in all directions. This scattering reduces picture brightness, wastes up to 90% of the viewable light, and wastes energy. Developing new types of screens, however, is costly, inefficient, and requires a longer period to recoup the investment than traditional sources of capital are willing to tolerate.

In 1994, Physical Optics Corporation (POC) sought to overcome the technical barriers to cost-effective production of a diffuser screen that uses beam-shaping technology to provide an intense, evenly distributed beam of light that is more than twice as efficient as previous diffusers. This enables a brighter, more intense image on the screen with a lower power requirement. Called Light Shaping Diffusers or LSD®, the technology employs holographically formed interference patterns to create the diffusing surfaces.

Laptop computers, flashlights, and projection-display screens are among the products that utilize holographic diffuser technology. Courtesy of Physical Optics.

The economic impact of this project has been significant: just two years after the project was completed in 1996, Physical Optics opened a $14 million production facility in California for the holographic diffuser and, by 2003, this factory was producing 100,000 parts per month. Enabled by this new mass-production capability, the POC light diffuser technology is being applied in such new and diverse markets as improved flashlights for aircraft inspection, enhanced blood analyzers, heat-resistant directed lighting, automotive dashboard display panels, semiconductor mask homogenizers, credit card security products, data-storage, and bar-code readers. Perhaps the biggest impact has been in color cell phone displays, where, according to Physical Optics, the technology is currently utilized in 45% of all color cell phone displays worldwide. Physical Optics has also created a spin-off corporation Optikey to commercialize the technology for security and authentication markets.

System Integration

Ten (10) systems integration awards were funded, representing approximately **$107.8 million** of total R&D innovations. Specific integrated systems technologies included systems that combine innovations in image capture with new image processing techniques. Example applications of these technologies included condition-based maintenance, quality control, and new medical imaging techniques.

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17 Project Brief: http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=93-01-0205
Gem: http://www.atp.nist.gov/gems/po-93-01-0205.htm
Status Report: http://statusreports.atp.nist.gov/reports/93-01-0205.htm

Smartsmith: Imaging-based High-temperature Deformation Process Control System

OG Technologies, Inc. (Ann Arbor, MI) was awarded $2 million over 3 years in November, 2000 to develop the first imaging-based system capable of modeling and controlling the deformation processes of ultrahot metals in forging and rolling, reducing waste by 90%, saving billions of dollars and reducing burn injuries in the work force.[18]

The operational efficiency of the steel and forging industries has been limited in part because inspection of forged metal at high temperature could only be done manually, with inadequate accuracy and slow processing. This results in thousands of tons of processed materials that must be scrapped and an enormous amount of wasted energy, which the U.S. Department of Energy estimates at 6 trillion BTU per year.

To address this problem, as well as worker-safety issues, OG Technologies Inc., in conjunction with experts from the Ohio State University and the University of Michigan, proposed a novel approach to develop an imaging/process-control system for high-temperature sensing and process inspection. The result was incorporated in the HotEye™ system and capable of monitoring the deformation processes of ultra-hot metals in forging and rolling. Prior to this technology, surface defects such as cracks could not be detected until after processing was complete and the product cooled down for inspection. Using HotEye™ allows better process control through earlier, and safer, defect detection, reducing cool-down delays while improving product quality.

Steel being coiled. Courtesy of OG Technologies, Inc.

The technology developed through the project has generated a great deal of interest from previously hesitant forging and rolling companies. OG Technologies collaborated with many different industrial partners in the U.S. and has expanded operations in Canada, South America and Asia. The impact on the U.S. economy could be significant. Using data from one test site and studies based on Department of Energy methodology, OG Technologies calculated the following potential impact on the U.S. economy:

- 500 tons of scrap per month saved (about 2.2% of total production), which converts to $250,000/month in direct productivity increases; energy savings of 8 Billion BTU/month; and
- 230 tons/month of carbon equivalent emission reduction.

OG Technologies is also applying this inspection technology to further upstream steps in the steel-manufacturing process, so the benefits of material scrap reduction, energy saving, improved quality, and safer inspection could become greatly enlarged in the near future.

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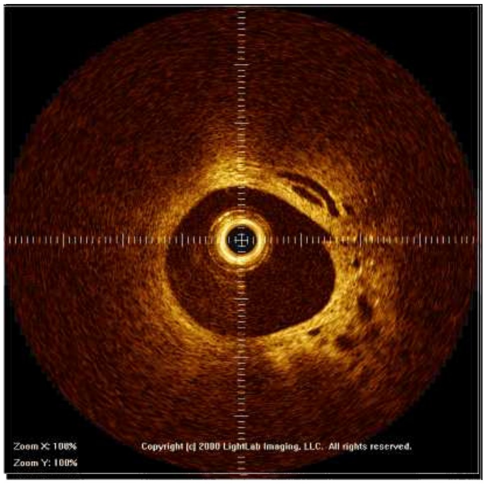
18 Project Brief: http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-3945
Gem: http://www.atp.nist.gov/gems/og_00-00-3945.htm

Development of Next Generation OCT Technology

Lightlab Imaging, Inc. (Concord, MA) was awarded $1.8 million over 3 years in November 1998 to design and demonstrate new system concepts and components that dramatically improve image quality and optical delivery mechanisms for optical coherence tomography (OCT), a new medical imaging technology that could have a major impact similar to that of X-ray computer tomography, MRI, and ultrasound.[19]

According to the National Institutes of Health, "biomedical imaging is an indispensable tool for the diagnosis and treatment of a variety of diseases."[20] Better biomedical imaging systems can enable healthcare practitioners to deliver better disease diagnosis and treatment.



In-vivo OCT image of a swine bile duct, for use in cancer detection. Courtesy of Lightlab Imaging, Inc.

OCT produces high-resolution, real-time, cross-sectional images of the internal microstructure of human/biological tissues, biological specimens, and other materials using infrared (IR) light. OCT is non-contact and achieves resolution in the two to ten micrometer range – 10-100 times better than ultrasound or other tomographic imaging technologies such as CT or MRI.

In 1998, LightLab Imaging proposed to develop a complete new OCT system, advancing and integrating multiple innovative components to make an OCT system practical for medical applications. During the project, LightLab Imaging developed new high-power, high-resolution optical sources; low-cost video-rate scanning modules; advanced signal-processing algorithms and hardware; and new probe modules including catheters, endoscopes, and handheld units. They then integrated these innovative components into a complete OCT system.

The company is now commercializing the resulting system. The unique features of OCT technology can be applied to a wide range of medical and non-medical applications, including provision of diagnostic information in situations where conventional biopsy is hazardous or impossible. In 2002, the company performed the first U.S.-based clinical investigation for their OCT imaging platform at Rhode Island Hospital. The study evaluated the feasibility of using the technology to obtain a better understanding of cardiac anatomy, particularly arterial plaques, and to enable better cardiac therapies such as stent placements in selected patients.

Approval of the OCT systems for sale in the U.S. is pending FDA clearance. The LightLab OCT coronary imaging system is currently approved for sale in the European Union, China, and Korea. During the last 3 years, the system has been used to guide coronary interventions in over 700 patients.

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19 Project Brief: http://jazz.nist.gov/atpcf/prjbriefs.cfm?ProjectNumber=98-01-0163

20 National Institute of Biomedical Imaging and Bioengineering http://www.nibib.nih.gov/About/Overview/Introduction

Appendix A: Table of Imaging Projects

Lead Organization	Project Title	Award Dates	Project Number	Lead State
Image Capture				
Corning Corp.	Advanced Technology for Microchannel Plates	1993-1995	1992-01-0124	MA
Cross Match Technologies	Authorizer Sensor	2001-2004	2001-1E-4392	FL
General Electric Company	Affordable Open MRI for Unserved Markets	2001-2004	2001-2E-4518	NY
General Electric Company	Low-Cost Amorphous Silicon Manufacturing Technology	1995-2000	1995-01-0152	NY
Intevac, Inc.	Low-Cost, Low Light Level Video Camera	1999-2002	1999-01-2017	CA
Lucent Technologies, Inc.	Fabrication and Testing of Precision Optics for Soft X-Ray Projection Lithography	1991-1994	1990-01-0121	NJ
Micro Magnetics, Inc.	Spintronics-Based High-Resolution, Non-Invasive, and Ultrafast Metrology for the Semiconductor Industry	2003-2006	2002-3E-5866	MA
Supertron Technologies	Superconducting Magnetic Resonance Imaging (MRI) Array Coil	2003-2007	2002-2E-5492	NJ
Teledyne Electronic Technologies	Novel X-Ray Source for CT Scanners	1995-1998	1995-01-0060	CA
Xerox Palo Alto Research Center	High Performance Sensor Arrays for Digital X-Ray and Visible Light Imaging	1997-2002	1996-01-0257	CA
Xradia, Inc.	Achromatic Fresnel Optic for EIV and X-Ray Radiation: An Innovative Camera Concept for Next Generation Lithography	2002-2005	2002-1E-5373	CA
Image Processing: Analysis and Extraction				
3D Geo Development	Automated Wave-Equation Imaging for Oil and Gas Exploration	2004-2006	2004-1I-6033	CA
ActivEye, Inc.	Active Alert for Video Monitoring	2003-2006	2002-3I-5980	NY
Advanced Digital Imaging Research	3-D Face Recognition for Security Screening	2004-2007	2002-3I-5879	TX
Bio-Rad Laboratories	Molecular Cytogenetics Using the GeneScope: An Ultrafast Multicolor System for Automated FISH Analysis	1995-1998	1994-05-0017	CA
Communication Intelligence Corp.	New User-Interface for Computers Based on On-Line Handwriting Recognition	1991-1993	1990-01-0210	CA
Communication Intelligence Corp.	Pen-Based User Interface for the Emerging Chinese Computer Market	1993-1996	1993-01-0211	CA

Lead Organization	Project Title	Award Dates	Project Number	Lead State
Geometric Informatics, Inc.	Geometric Surface Classification and Identification by Conformal Structure	2004-2007	2002-3I-5741	MA
Geometrix, Inc.	Robust Extraction of 3D Models from Video Sequences	1999-2002	1999-01-3012	CA
Imaging Therapeutics, Inc.	Novel Internet Enabled Techniques for Diagnosis and Management of Patients with Arthritis	2000-2003	2000-1C-4357	CA
Imaging Therapeutics, Inc.	Novel Low-Cost Techniques for Diagnosis and Management of Patients with Osteoporosis	2002-2007	2001-4I-4639	CA
Infrared Identification, Inc.	The Next Generation Biometric-Infrared Identification: Accurate, Fast, Scalable and Secure	2003-2006	2002-3I-5680	VA
Markland Technologies	Expanding Facial Recognition Capability with Novel 3D Imaging Technologies	2002-2006	2002-1I-4988	MD
NSA Geotechnical Services, Inc.	Integration of 3-D Ground Imaging Technologies with Numerical Modeling for Civil Construction Design	2001-2004	2001-1I-4391	CO
Perceptron, Inc.	Robust, Fast 3-D Image Processing and Feature Extraction Tools for Industrial Automation Applications	1994-1996	1993-01-0071	MI
Raindrop Geomagic, Inc.	Automated Whole Part Inspection for Manufacturing Process Control	2003-2006	2002-3I-5821	NC
Resolution Sciences Corp.	Creation of a National Digital Tissue Repository	1998-2001	1998-01-0064	CA
Sonic Foundry Media Systems	Integrated Speech, Language, and Image Processing for Real-Time Creation of a Videoconferencing Library System	1999-2002	1998-04-0016	PA
StreamSage, Inc.	Automated Topic-Specific Indexing of Rich Media	2001-2004	2001-2I-4500	DC
Videomining	Enabling Personalized Multimodal Access for People with Severe Communication/Motor Disabilities	2004-2007	2004-1I-7036	PA
Image Processing: Information Insertion				
Brainstorm Technology, LLC	Integration of 3-D Photography for Photorealistic Modeling in Construction and Disaster Recovery	2003-2006	2002-3I-5686	NY
Dolby Laboratories	Content Specific Camcorder Jamming for Digital Projectors	2002-2005	2002-1I-5237	VA
Sarnoff Corp.	Secure, Robust, Forensic Watermarking	2001-2003	2001-2I-4499	NJ
Tektronix	Advanced Distributed Video ATM Network for Creation, Editing and Distribution	1995-1998	1995-04-0027	CA
Image Processing: Transformation				

Lead Organization	Project Title	Award Dates	Project Number	Lead State
C Video, Inc.	Adaptive Video Codec for Information Networks	1995-1998	1995-04-0008	CA
Demografx	Integrated Layered Compression System Prototype	1999-2000	1998-04-0006	CA
FastVDO, LLC	High-Definition Video Disc (HDVD)	2004-2007	2002-3I-5664	MD
Mathematical Technologies, Inc.	Mathematical Algorithms and Software for the Restoration and Reformatting of Moving Pictures	1993-1995	1992-01-0053	RI
Media BIN, Inc.	High Fidelity Digital Image Compression	1992-1995	1991-01-0057	GA
Physical Optics Corporation	Compressed Live Object Video Interactive Singular (CLOVIS) Technology	1999-2002	1998-04-0007	CA
Quantum Signal, LLC	Robust, Multi-Modal Biometric Algorithm Technology	2002-2005	2002-1I-5004	MI
Utopia Compression Corp.	An Advanced Disruptive, Intelligent-Based Image Compression Technology	2003-2006	2002-1I-4936	CA
Image Processing: Virtual Reality				
Aesthetic Solutions	A Component Technology for Virtual Reality (VR) Based Applications	1995-1998	1994-06-0007	CA
Engineering Animation	A Three-Dimensional Database for Visualization of Human Physiology	1992-1995	1991-01-0184	IA
Immersion Technologies	Teleos™: An Authoring System for Virtual Reality Simulations	1995-1998	1995-10-0059	MD
Immersion Technologies	PreOp: The Pre-Operative Decision Support System	1997-1999	1997-03-0083	MD
Industrial Virtual Reality	Virtual Reality Anthropomorphic Avatars for Scalable Telecollaboration Including Wireless and Other Low-Bandwidth Devices	2001-2004	2001-1I-4384	IL
Searle	Virtual Reality Telecolalborative Integrated Manufacturing Environment	1997-2000	1997-05-0006	IL
Yantric, Inc.	Virtual Reality Based Surgical Simulation and Training System	2003-2006	2002-3I-5724	MA
Zoesis	Advanced Interactive Characters	2002-2005	2002-1I-5225	MA
Image Transmission				
Intersil Corp.	Mobile Information Infrastructure for Digital Video and Multimedia Applications	1995-2000	1995-04-0001	FL
Picolight	Ultra-Compact Packaging Technology for Telemedicine, Telecommunications and Next Generation I/O (NGIO)	1999-2002	1999-01-2029	CO
Sarnoff Corp.	Video Enhanced Residential ADSL Broadband	2003-2006	2002-3I-5676	NJ

Lead Organization	Project Title	Award Dates	Project Number	Lead State
Sarnoff Corp.	HDTV Broadcast Studio	1995-2000	1995-04-0026	NJ
Telcordia	Interoperability Tools for Digital Video Systems	1995-1997	1995-04-0029	NJ
Image Presentation				
3D Technology Laboratories	Improved Materials Performance for Market Penetration of Crossed Beam Volumetric Displays	1998-2001	1998-01-0086	CA
Actuality Systems	Spectrally-Multiplexed Holographic Video	2003-2006	2002-3E-5983	MA
ColorLink, Inc.	Color Sequential Imaging	1997-2000	1996-01-0263	CO
Displaytech, Inc.	FLC/VLSI High-Definition Image Generators	1995-1997	1994-01-0402	CO
eMagin Corp.	Large Area Digital HDTV Field Emitter Display Development	1994-1997	1993-01-0154	NY
eMagin Corp.	Technology Development for the Smart Display – A Versatile High-Performance Video Display Integrated with Electronics	1995-1999	1995-01-0126	NY
Imaging Systems Technology	Low-Cost Flexible Plasma Displays	2003-2006	2002-2E-5424	OH
Kopin Corp.	Scalable High-Density Electronics Based on MultiFilm Modules	1992-1995	1991-01-0262	MA
Kopin Corp.	High Information Content Display Technology	1995-1998	1994-01-0304	MA
Photera Technology	High Resolution Mutlimedia Laser Projection Display	1995-1997	1994-01-0133	CA
Physical Optics Corporation	Holographic Graded-Index Non-Lambertian Scattering Screens and Components with Light-Shaping Capability	1994-1996	1993-01-0205	CA
SI Diamond Technology, Inc.	Diamond Diode Field Emission Display Process Technology Development	1995-2000	1994-01-0282	TX
Zebra Imaging	Rapid Full-Color Digital Hologram Recorder	2004-2006	2002-3E-5931	TX
System Integration				
Chemicon	Chemical Imaging for Semiconductor Metrology	1998-2001	1998-02-0055	PA
KLA-Tencor Corporation	Advanced Wafer Inspection for Next-Generation Lithography	2000-2003	2000-1B-4243	CA
KLA-Tencor Corporation	Intelligent Mask Inspection for Next-Generation Lithography	1999-2004	1998-06-0057	CA
LightLab Imaging, Inc.	Development of Next Generation OCT Technology	1998-2001	1998-0100163	MA
Markland Technologies	A Novel Intraoral Three Dimensional Digitizer for Digital Dentistry	2000-2003	2000-1B-4140	MD

Lead Organization	Project Title	Award Dates	Project Number	Lead State
Newport Sensors, Inc.	Microwave Imaging Technology for Condition Assessment of FRP Composites	2003-2006	2002-3C-5939	CA
OG Technologies	Smartsmith™: An Imaging-Based High-Temperature Deformation Process Control System	2000-2004	2000-1C-3945	MI
Sarnoff Corp.	Advanced Vision-Radar Threat Detection (AVRT): A Pre-Crash Detection and Active Safety System	2004-2007	2004-1E-6172	NJ
SurroMed, Inc.	Blood “Fingerprinting”: A First Step Toward Personalized Medicine	2001-2005	2000-1A-4106	CA
Varian Medical Systems	Novel X-Ray Security Systems: Fast, Accurate and Affordable	2003-2007	2002-3E-5875	CA

Appendix B: Additional Reports

Further information on other advanced imaging systems projects in addition to the references in the main text:

A Technology Boost for U.S. Manufacturers of Flat Panel Displays
American Display Consortium, Northwood, OH
Status Report: http://statusreports.atp.nist.gov/reports/90-01-0060.htm

LCOS Technology Expands Potential of Color Imaging and Display
Colorlink, Inc., Boulder, CO
Status Report: http://statusreports-atp.nist.gov/reports/96-01-0263.htm

Computer Recognition of Natural Handwriting
Communication Intelligence Corporation, Redwood Shores, CA
Status Report: http://statusreports.atp.nist.gov/reports/90-01-0210.htm
Gem: http://www.atp.nist.gov/gems/cic-90-01-0210.htm

Three-Dimensional Anatomy of Human Body, With Animation, for Medical Training
Engineering Animation, Ames, IA
Status Report: http://statusreports.atp.nist.gov/reports/91-01-0184.htm

Mathematical Technology to Restore or Enhance Movies
MTI, Inc., Providence, RI
Status Report: http://statusreports.atp.nist.gov/reports/92-01-0053.htm

Diamond Diode Field Emission Display Process Technology Development
SI Diamond Technology, Inc., Houston, TX
Status Report: http://statusreports.atp.nist.gov/reports/94-01-0282.htm
Gem: http://www.atp.nist.gov/gems/npi_94-01-0282.htm

Machines that See in 3-D
Perceptron, Inc., Plymouth, MI
Status Report: http://statusreports.atp.nist.gov/reports/93-01-0071.htm

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