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CAT-Scanning Iraq

What has changed fundamentally in the last decade isn't our power to strike precisely— it's our power to see what needs to be struck.

We don't normally begin with observations from TV correspondents, but James Oberg of NBC News has a rock-solid technical background, and his report came, coincidentally, in the middle of our own exploration of spectral imaging. "The search for debris from the space shuttle Columbia is receiving valuable support," Oberg reported on March 27, "from a little-advertised U.S. Army sensor program whose important role has remained unsung, probably due to security concerns connected with the sensor's primary mission to detect land mines in combat zones such as Iraq."

As Oberg reported, the Compact Airborne Spectral Sensor (Compass) is about the size of a breadbox and weighs less than 100 pounds. For the Columbia search, it was mounted on a vintage DC-3, which flew across western states at an altitude of about 2,000 feet, measuring electromagnetic radiation reflected from the surface in 256 different wavelengths. Compass collects data for up to four hours; ground computers then crunch the massive amounts of data to produce terrestrial maps showing possible hits. On March 21, those maps guided ground teams to three pieces of shuttle tile that were only a few inches across.

Oberg's report hints at something that has changed fundamentally in the last decade in both civilian and military technology. It isn't just our power to strike precisely — it's our power to see what needs to be struck. That smart bombs can now strike with truly surgical precision was news ten years ago, in the first Gulf War, but no longer is today. The "fog of war" is giving way to extraordinary power to formulate images and collect information across huge swaths of the electromagnetic spectrum. Call it omni-spectral sensing.

Fog itself is opaque to light, but transparent to many other bands of the electromagnetic spectrum. The same is true for dust, smoke, and foliage. And when there is little or no visible light at hand to illuminate what you want to see, there generally is heat (infrared radiation) and — on the battlefield most especially — a cacophony of emissions from communications radios, radar, guidance systems, and countless other electronic devices. Scan across the broadest possible range of wavelengths, analyze the signals you pick up with extremely powerful computers and software, and you can see almost anything, anywhere. The world around us telegraphs, radiates, and thus reveals its presence, by the power it continuously emits, in every color of the electromagnetic rainbow.

Which brings us to Sensytech (STST). This is the first issue we've written about a company whose business remains, for the most part, highly classified. The company tells Wall Street little more than that it is involved in "electronics and technology products for the defense and intelligence markets." It counts as its main customers the large military systems integrators — Northrop Grumman (NOC) and L-3 Communications (LLL), for example. Some 60 percent of Sensytech's revenues come from sole source contracts — a remarkable figure in itself, considering the Defense Department's strong aversion to sole-sourcing anything.

Sensytech has been in business for 30 years, achieving by last year $40 million in sales. That's modest by defense leviathan standards, but the company is now perfectly positioned, in our view, for very rapid growth. Sensytech is, without doubt, one of the leading players in spectral imaging.

Active Imagers

When we wrote about X-ray scanners in December 2001 (X-Ray Vision), we were examining the state-of-the-art technology for mono-spectral analysis. The engines that power the X-ray scanners in airports, like CAT scanners in hospitals, direct a finely tuned, single-frequency beam at a nearby target. Then, as now, we liked Analogic (ALOG). The company's intellectual property is firmly anchored in the computing and software aspects of computer aided tomography. Last month, Analogic announced its next-generation machine — a smaller, faster, better unit suitable for scanning carry-on bags.

As we discussed then, the basic physics of molecular fingerprinting has been well understood for decades. Atomic nuclei, entire atoms, and molecules are like tuning forks - hit them with an incoming photon at the right frequency, and they hum, vibrate, and kick back one or more photons at different frequencies. X-rays are so powerful that they can be used to probe the nucleus itself. Softer forms of radiation disclose information about electron shells and complex molecular structures.

The capabilities for exploiting these phenomena to analyze even the tiniest traces of molecules were incorporated years ago into large, expensive, laboratory instruments. But performing such analyses quickly, cheaply, and at a distance is a very different challenge. Imagine trying to discern molecules, shards, and small structures not inside a patient on a nearby stretcher, but fragmented, vaporized, and dispersed across hundreds of acres of land, or scattered on the surface of the water or in the air.

LIDAR — light detection and ranging — is probably the closest remote-sensing analogue to the CAT scanner. LIDAR is much like radar, but with radar's radio-band transmitter replaced by a laser operating in one specifically selected band in the ultraviolet, visible, or infrared region of the electromagnetic spectrum. The first LIDAR system was built in 1964, using a ruby laser. Today's LIDAR sensors are used for atmospheric sensing, ground mapping, and will soon be mounted on the remotely operated vehicles that do the heavy lifting on the seabed, 5,000 feet below the production rigs that pump the oil (Electricity to Oil, June 2002).

Only a handful of companies make LIDAR units, a number of them mainly for military customers. A division of Coherent (COHR) (Photon Power, July 2001) is a leader in the field, packaging the company's world-class diode lasers into LIDAR systems. It is joined by a few smaller players, such as ORCA Photonics Systems, Q-Peak (part of private Physical Sciences Inc.) and Optech (Canada). In field trials at Dugway Proving Ground in Utah, world-class Coherent Technologies (private, and not to be confused with Coherent Inc. just noted) recently demonstrated a LIDAR system designed for the military to detect and track chemical and biological toxins. The company's "WindTracer" unit generates high-resolution 3-D maps of aerosol plumes and wind direction.

DIAL (Differential Absorption LIDAR) takes a major step beyond LIDAR: It pulses laser light at two different colors (i.e., wavelengths), one of which is absorbed by the molecule of interest, the other slightly different color is not absorbed and establishes a clear baseline. The difference in intensity of the two return signals provides information on the concentration of the target molecule. LIDAR is tuned to a specific signature, so a specific laser is needed for each application.

One possibility for expanding LIDAR's target menu is to use a single, tunable laser. A portable sealed-CO2 laser developed by Raytheon (RTN) for example – the Frequency-Agile Laser Sensor — has a six-mile range and produces laser pulses across a 20-wavelength band. The "Warning and Identification LIDAR Detector for Countering Agent Threats" (WILDCAT) jointly designed by Raytheon and STI Optronics is likewise built around a rapidly tunable CO2 laser. The Army's main R&D outfit in this arena, the Edgewood Chemical Biological Center, is developing another demonstrator — the Standoff Handheld Real-time Early Warning Detector (SHREWD). Built around solid-state lasers, SHREWD will yield a light-weight 30-lb system, with a three-mile range, intended for use by soldiers and unmanned aerial vehicles.

Colors in the Distance

Like radar and flash-lamp photography, LIDAR and DIAL are active — they direct beams at targets and look for reflections. This kind of sensing can be both very sensitive (the brighter your light, the lower

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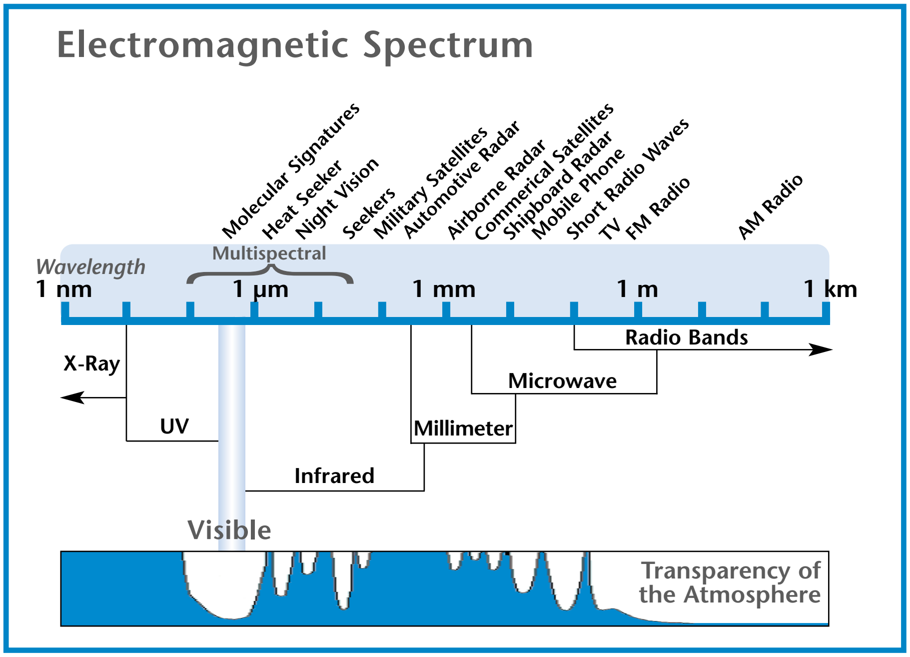
the concentration you can detect) and very specific (a precisely tuned laser reflects off some molecules and not others). But for the same reason, such systems can typically detect only a quite narrow range of molecules, and they also announce their presence to any hostile observer on the far side of the beam. Passive systems, by contrast, rely on ambient light and heat for illumination. They are less sensitive in some respects, because they pick up much weaker signals. But they can also pick up frequencies across very wide spans of the electromagnetic rainbow and cover much broader slices of territory.


Electromagnetic Spectrum

The dozens or hundreds of bands sampled typically range from ultraviolet through the visible and into the long-wave infrared, and rely on passive solar radiation for their lighting. The more wavelengths they measure, the more finely they can discriminate between different molecules and materials. Gold and silver are both shiny; distinguishing between the two begins with distinguishing between a yellow shine and a white one, and proceeds from there. Detect enough different wavelengths, and you can distinguish the spectral signatures of a wide variety of substances, and also estimate the abundance or concentration of materials, based on how much radiation is absorbed, in which wavelengths. The larger and more complex the molecule, the more colorful and thus distinctive the signature.

Multispectral scanning was pioneered by NASA, initially to map materials on the Earth's surface. The development of remote chemical detectors began in the late 1950s, using infrared technology. The unique molecular signatures of molecules in different plants, soil, water, and minerals can be distinguished by parsing the spectrum into multiple bands, on both sides of the visible spectrum; remarkable, false-color images can then reveal chlorophyll, toxins, pollution, and the heat produced by blight or the infestation of insects. For the military, multispectral images readily expose the enemy's camouflage. Molecular differences in atmospheric chemistry can reveal plumes of industrial pollution or enemy poisons. Molecular differences in soil chemistry reveal nutrient concentrations for farmers, or evidence of the recent digging of bunkers or land mines for soldiers.

Multispectral instruments are widely employed today. Beginning in the late 1980s, an even more sophisticated variant emerged — hyperspectral imagers, which collect data in at least fifty, and up to hundreds, of narrow, contiguous wavelengths. NASA again led the way, pioneering development of hyperspectral remote sensing for mapping and monitoring Earth resources. The first space-borne hyperspectral platform was launched in 1997 (though the satellite in question failed). In November 2000, NASA's EO-1 Hyperion Sensor 5 was the first satellite actually to collect hyperspectral data from space. The use of multi- and hyperspectral imagers for agriculture and mineral exploration continues to grow steadily. Emerging applications include those in medicine, manufacturing, pharmaceuticals, art restoration, and archaeology.

From Theory to Practice

The "T" in CAT-scanning stands for "tomography," meaning to slice through (tomos) and make a picture. The "CA" stand for "computer aided." It takes astonishing amounts of computing power to synthesize the torrents of data from thousands of separate slices into a coherent 3-D picture – and even more to use CAT to find the invisible signature of explosives in packages or luggage. As we discussed in our Analogic issue, a medical-derived CAT scanner uses a massive robotic arm to spin an X-ray machine around a target package, generating 200+ Mb-per-second data streams to be assembled into a final image.

A multispectral imager can be considerably more demanding than that, and hyperspectral systems even more so. A hyperspectral system must generate — and then make sense of — what engineers in the business call a "hyperspectral image cube." Start with the three spatial dimensions of the space to be imaged.

For every point — pixel — in that cube, sensors can detect emissions of dozens or hundreds of separate wavelengths. To image movement — to produce a movie, rather than just a static picture — there's the time dimension to track as well. The resulting data stream is the equivalent of stacks upon stacks of separate 2-D snapshots, each one representing a different slice through the cube, at a different frequency, at a different moment in time.

A multispectral "camera" must, in effect, function like dozens, or hundreds, of discrete, finely-tuned cameras, all running simultaneously and in parallel. An ordinary color camera manages to sample just three wavelengths (the primary colors) through the clever use of filters and a three-layered film or photoelectric sensor. A quite different approach is needed, however, to sample hundreds.

Incoming light is split into the target bands using highly sophisticated optics including a dichroic beam splitter (think of the entire construct as a highly sophisticated and exceptionally finely tuned kind of prism that divides light into its constituent colors). Each separate band is sent through its own focusing optics to a separate detector, and hence to separate data processing channels.

While similar components and analytical methodologies are used for many different applications, much of the design optimization is still application-specific. Sensing in bands from ultraviolet down to near-infrared is possible with silicon-based charge-coupled devices. But longer wavelengths require special infrared detectors made from more exotic semiconductors, such as indium antimonide (for wavelengths around 2 to 5 microns), or mercury cadmium telluride (in the 8 to 14 micron deeper infrared window) – and dozens of (expensive) separate detectors are needed for each finely parsed line in these bands. Multispectral imagers frequently require the custom fabrication of both specialized detectors and optics.

As currently designed, multispectral imagers range in size from the compact, low-end units (low resolution and fewer bands), to large multispectral cameras, up to hyperspectral systems weighing hundreds of pounds that gobble kilowatts of power and require a phalanx of lenses and sensors, electronically tunable filters, processors, and power supplies. Prices range from $200,000 up to a $1 million and more. Multi- and hyperspectral imaging ultimately depend on the optimal integration of a complex array of components — filter, camera/sensor, optics, data acquisition, and software. When the imager is mounted on an aircraft or vehicle, very sophisticated techniques are also required to remove vibration and jitter that would otherwise hopelessly blur the images. Additional data integration may also come from data fusion with collaterally flown LIDAR (to generate precise altitude information).

Software is all-important. The software must control and synchronize the tunable filter, camera, and data-acquisition electronics. Then it must process the data. High-speed electronic filters generate huge volumes of data that require extremely sophisticated data compression algorithms (to compress the flood of data), as well as analysis tools and front-end integration with user-friendly interfaces. As with X-ray CAT scanning, the design of efficient data-processing engines and look-up tables requires a deep understanding of materials and targets to be imaged, and of the sensors being used to pick up radiation. The chemical signature of a methyl benzoate molecule is unique and quite different from that of benzaldehyde.

Sensytech

Sensytech's main business — accounting for 80 percent of its sales – appears, at first blush, to have little to do with multispectral imaging. The company's expertise is centered on a different part of the electromagnetic spectrum — radar threat-warning systems and communications reconnaissance systems. Military radar and communications systems operate over a very wide range of radio wavelengths – a thousand-fold wider than the dial on your car radio, and at different power levels with different modulation schemes.

From individual soldier, to armored vehicle, to helicopter or fighter, different platforms project power in different bands, and they do so for different purposes — communications, surveillance, target acquisition, and so forth. If every wavelength were a different visible color, the battlefield would look like a riot of different hues sprayed and splashed over the canvas of the Iraqi desert and the waters of the Persian Gulf, filling the entire sky with a rainbow of pigment. Sensytech builds equipment that sees all those colors, and interprets them. It does to electromagnetic colors what a bloodhound does to scents. Thus, for example, racks of electronic hardware built by Sensytech are found on every type of Naval vessel and aircraft.

Sensytech got into imaging only in 1998, when it merged with Daedalus Enterprises, the leading multispectral imaging company, and manufacturer of the world's leading airborne hyperspectral systems. With that transaction, the then-private S.T. Research adopted its current name, Sensytech, and became a public company (Daedalus was already publicly traded). Daedalus, which had been exclusively focused on commercial imaging, now had a direct opening into defense and security markets. Today, imaging for both military and commercial applications accounts for about 12 percent of Sensytech's revenues.

But marketing opportunities were secondary; there's a single high-tech expertise at the core of everything Sensytech now does. Before the Daedalus merger, the company built detectors that captured multiple wavelengths, from meter-long radio waves all the way up into the exotic millimeter bands, the latter occupying a strange (and remarkably useful) part of the spectrum adjacent to very deep infrared. (*The Power of Millimeter Waves*, November 2001.) Daedalus extended the company's range, into the directly adjacent infrared, visible, and ultraviolet bands.

The combined company is an ultra-high-tech snoop. It builds technology that extracts information not from the information deliberately encoded in a signal, but from the patterns and trajectories of electromagnetic power itself. Sensytech's radar and communications tools are multi-spectral detectors and analyzers in the radio bands; its imagers are multi-spectral detectors higher up the dial. To be sure, there are differences in the sensors and filtering systems used to gather the incoming photons — radio antennas and infrared detectors look quite different — but so far as the basic physics goes, they perform identical functions, and the analytical software behind them share much in common. There are fundamental similarities in the CPUs and software used to make sense of multispectral data flows, and there are, as well, powerful synergies in bringing military-bred skills for reducing weight and increasing robustness. Sensytech is now one of a very few firms that can be said to build "omni-spectral" processing tools.

There are fundamental similarities in the CPUs and software used to make sense of multispectral data flows.

Organized around the demands of its customers, Sensytech has three corporate divisions: Defense, Communications, and Imaging. But the company itself describes its business as the provision of "total system solutions across the electro-magnetic spectrum for electronic warfare applications, communications intercept and airborne imaging." All of its products are built around tools that search for, intercept, locate, read, and analyze electromagnetic signals. In the radio bands (for radar and communications), Sensytech builds RF Testing units (from 500 MHz to 94 GHz, the latter quite a way up the spectrum from the 1 GHz cellular range) and threat warning receivers. In the imaging bands, it manufactures panchromatic and multispectral digital cameras, multispectral and hyperspectral scanners, and image processing and analysis devices.

Sensytech has also extended its signal processing expertise into the acoustic arena and sonar systems — including those used for torpedo countermeasures. In February 2002, Sensytech purchased the electronic defense division of Frequency Engineering Laboratory, a specialist in torpedo countermeasures. Later that year, Sensytech won $12-million in two programs for surface-ship torpedo defense, directly from the U.S. Navy and via General Dynamics (GD). The engineering and software algorithms that can extract information from noise can also generate noise to prevent sensors in hostile hands from doing the same — hence the countermeasures side of the business. Sensytech also makes an acoustic system that can scramble the sounds of conversations that would otherwise leak out of a room.

When Sensytech acquired Daedalus in 1998, interest in military technology was flagging. Daedalus had begun the development of multispectral tools for agricultural and geological mapping with NASA more than a decade earlier, and the timing was just right for making a move into civilian markets. Only very recently has the cost of computing dropped far enough to begin to make the analysis of multispectral signals more affordable and portable. And only in the last few years have sensors capable of picking up signals across multiple wavelengths grown sufficiently cheap and accurate to begin to make the prospect of multispectral sensing affordable as well. The advent of readily affordable digital maps and GPS was a third essential development in the advance of multispectral imaging.

Today, Synsytech sells a wide range of imagers and digital cameras, from a simple bispectral unit to a hyperspectral commercial scanner that tracks up to 120 bands in the infrared, visible, and ultraviolet. The company's imaging focus has been on commercial markets for the detection and analysis of plant and forest disease, firefighting (multispectral imagers can see through smoke and heat to pinpoint critical location of an advancing fire front), mineralization, surface groundwater and spring mapping, and oil and chemical spills. These areas remain an important part the company's future imaging business; the company shipped multi-million dollar hyperspectral imagers a year ago, for example, as key parts of the Brazilian System for Vigilance of the Amazon. For domestic customers who can't afford or who don't need to own the hardware, Sensytech offers a turnkey airborne imaging service. The service has been used, for example, to track walrus in Alaska, fresh water springs in Florida, and map out new highways in Ohio.

Today, of course, nearly all of these commercial capabilities are of greatly renewed interest to both homeland security and military customers. Sensytech imagers can inspect commercial, industrial, and residential facilities, power networks, pipelines, railroads, and highway systems; they have also been used, more recently, in drug interdiction, coastal patrol, border surveillance, search and rescue, crevasse detection, and land-mine detection. The company has sold systems to an unnamed government for coastline border patrol. A sensitive multispectral camera can detect the wake of even a small boat up to two hours after it was created.

Now, post-9/11, Sensytech has launched a major internal development effort to reduce the weight of its multispectral imagers, and to increase power with more on-board data processing. (The current approach of collecting gigabytes for post-flight processing is tolerable in surveys and analysis, but doesn't meet the imperatives of real-time defense and security, or it turns out for that matter, for fighting forest fires.)

Sensytech says its main focus now is to produce a system suitable for Unmanned Aerial Vehicles (UAVs). While UAVs such as the Predator and Global Hawk have recently won a lot of notice in military conflicts, homeland security and border patrol are equally important – and probably much larger — markets. Efficient data compression is a high priority for real-time imagers mounted on small UAVs; without it, the data downlink simply chokes on the limited available bandwidth. Sensytech is bringing to bear its defense-derived sophisticated on-board electronics so that the device can downlink processed — rather than raw — data.

Sensytech's declared objective is to position itself as the pre-eminent supplier of airborne multispectral tools for homeland security. The company sees the opportunity to consolidate its control of this nascent but rapidly emerging technology. At the end of last year, Sensytech raised $18 million in a secondary offering to support these and other development efforts and additional acquisitions. In February, the company announced plans to purchase the ($10 million sales, private) Codem Systems, a specialist in antenna systems, radio monitoring, geolocation, and frequency management systems.

Other Players

Only a handful of other companies build high-end multi- and hyperspectral instruments. Raytheon and TRW (now Northrop) are players exclusively on the defense side, and primarily for very high-cost one-off systems for satellites and the like. A few small private companies serve the commercial market for mining, oil exploration, and environmental monitoring, with only occasional dabbling in the defense market — Canadian-based ITRES, HyVista (Australia), (U.S.-based) Opto-Knowledge Systems, and STI Industries (Hawaii).

Opto-Knowledge's flagship product, for example, uses hyperspectral imaging to permit "precision farming," that precisely and dynamically links the use of fertilizer and pesticides to soil and plant conditions in each part of a field. Several years ago, an Opto multispectral imager demonstrated an Intelligent Missile Seeker capability — used to distinguish the real target from decoys that are released to foil countermeasures. Using multiple spectral bands, the imager can, for example, discern exhaust water and CO2 emissions, allowing it to distinguish a real target's unique thermal signature from an incendiary decoy.

Biggest among the smaller, private players, STI Industries appears to be Sensytech's strongest competitor. Last year, for example, STI announced a successful airborne multispectral demonstration for the Navy that detected simulated submerged mines in the Patuxent River. A similar system can find and track submerged divers, and whales – both of which are of interest to the Navy, too.

A sensitive multispectral camera can detect the wake of even a small boat up to two hours after it was created.

All in all, however, Sensytech appears to have established itself solidly as both a technology and market leader. The company has a fleet of over 100 of the most sophisticated multispectral systems in the field. It is also a pure play in this very important, fast-emerging market of omni-spectral signal processing. Like many other companies with high-tech expertise in promising security and defense-related areas, Sensytech's revenues — and its stock price — have roughly doubled since 9/11. Homeland security and military customers will continue to fund the development, standardization, and shrinking platform, improving the flexibility of SynSyTech's imaging tools. And there is excellent reason to expect that demand in new civilian markets will emerge rapidly, moving multispectral imaging from today's expensive, custom applications into a more standardized and much larger market.

The Ultimate Camera

We've written before about the new sensors that now enable imaging in the infrared (Infrared Imaging; Sense Out of Chaos, January 2002), millimeter bands, (The Power of Millimeter Waves, November 2001), and X-rays (X-Ray Vision, December 2001), and that make possible electric weapons (The Electric Battlefield, December 2002) and precision guidance (Highly Ordered Power, October 2001). The military has always grasped the critical importance of acquiring information on the battlefield — the Compass unit used in the Shuttle search was developed at the U.S. Army's Electronic Sensors Directorate at Fort Belvoir, VA. Now, the battlefield is everywhere. In March, Secretary of Homeland Security Tom Ridge told the House Appropriations Subcommittee on Homeland Security that detection technologies top the list of R&D goals for the new Homeland Security Advanced Research Projects Agency (HSARPA).

Many of those detectors will be up-close scanners like the ones already used in airports to detect guns and explosives. Many others will have to be remote sensors that can scan large areas and volumes quickly and continuously for weapons the size of molecules and incendiaries the size of radioactive nuclei. A top priority for homeland defense is to be able to locate and track plumes — small, inadvertent ones that reveal the existence of production facilities, and larger, deliberate ones, that reveal a chemical, radiological, or biological attack. Before an attack occurs, information can be the springboard for preventing it; afterward, it is the key to rapid response (on the battlefield) and limiting panic (on the home front), and to organizing the necessary response.

Civilian uses of this technology, from industrial to medical, are expanding apace. While our perspective on "environmental" problems has matured a lot in recent months, the monitoring and tracking of ordinary industrial pollutants remains very important; many still view Dow and Detroit as greater threats to the planet than Al Qaeda and Saddam. When all is said and done, the multispectral imager is just the camera carried to its logical limit - to the point where "light" is collected across a range of wavelengths vastly broader than those visible to the human eye, and images are synthesized by digital machines vastly more intelligent (in this specific regard, at least) than the visual cortex of the human brain.

The tantalizing promise of multispectral imaging technology has been recognized for years. The main obstacle to its widespread deployment has been size, cost, and complexity. In the normal course of things, the technology itself and its applications would have emerged at a healthy but nevertheless deliberate pace. The pace is now accelerating, however. The price of the technology will continue to fall, the sensing and computing engines continue to shrink, and markets will grow rapidly. A new class of high-resolution low-cost lead-selenide infrared detectors, for example, will soon emerge. We ourselves have invested in the leading private company that's developing these as replacements for expensive mid-wave detectors, SensArray Infrared, which is partnered with the infrared group in BAE Systems (BA.L).

Building multispectral imagers is still much like building Formula 1 racecars - volumes are tiny, the devices are extremely complex. Nearly half of the cost is in the components, and a major share is tied up in application-specific custom engineering. But the costs of all the key components (sensors, filters, digital logic) are declining rapidly. Component capabilities are improving equally rapidly, and they are growing very much more flexible, thus reducing the need for application-specific customization. Multispectral imagers, in short, are now poised to make the transition from today's highly custom hand-built to more standardized, albeit still very expensive production. All the trends are toward smaller, cheaper, much more broadly functional units.

It won't be too long before LIDAR, DIAL, frequency agile, and other active-illumination detection systems are fully integrated with the passive systems to make full, simultaneous use of both background (solar) radiation and the beams that can be projected by lasers, millimeter wave radars, and conventional radar. Several years ago the Department of Energy established a multi-laboratory team (CALIOPE — Chemical Analysis by Laser Interrogation Of Proliferation Effluents) devoted to the advancement of laser-based remote sensing of both chemical and radiological materials. Most of the focus was on finding better, faster, more automated methods to analyze and extract information from data-packed hypercubes.

The realities of homeland security and the new of face war change things fundamentally. Imaging, tracking, remote sensing - these are now national security priorities, as urgent, in this new era of warfare, as the race to develop the first nuclear weapons was in the 1940s. The world we now occupy needs a lot more of this technology, and much sooner than anyone could have foreseen before 9/11. Sensytech's omni-spectral sensing and data processing expertise will play a central role in supplying the vision systems of the future.

Peter Huber, Mark Mills, April 2, 2003

The Power Panel

For an explanation of the ascendant digital power technology for each of these companies, see the indicated issue of the DPR.

FEATURED COMPANY	DPR ISSUE	OTHER PLAYERS IN THE ANALYZED SPACE*
II-VI (IIVI) www.iivi.com	1/03	Poly-Scientific (subs. Raytheon (RTN)); Umicore (Umicore Group, Belgium (ACUM.BE)
Advanced Power (APTI) www.advancedpower.com	12/00	Hitachi America (subs. HIT); Mitsubishi Semiconductor (subs. MIELY.PK); ON Semiconductor (ONNN); Philips Semiconductors (subs. PHG); Siliconix (SILI); STMicroelectronics (STM); Toshiba (TOSBF.PK)
American Superconductor (AMSC) www.amsuper.com	10/00	ABB (ABB); Intermagnetics General (IMGC); Waukesha Electric/SPX (subs. SPW)
Amkor Technology (AMKR) www.amkor.com	4/02	ChipPAC (CHPC); DPAC Technologies (DPAC)
Analog Devices (ADI) www.analog.com	8/01	Linear Technology (LLTC); Maxim Integrated (MXIM); STMicroelectronics (STM)
Analogic (ALOG) www.analogic.com	12/01	American Science & Engineering (ASE); Heimann Systems/Rheinmetall Group (subs. RNMBF.PK); InVision Technologies (INVN); L3 (LLL); Rapiscan/OSI Systems (subs. OSIS)
Applied Materials (AMAT) www.appliedmaterials.com	3/03	Novellus (NVLS); ASML (ASML)
C&D Technologies (CHP) www.cdtechno.com	7/02	East Penn (pvt.); Enersys (pvt.); Exide (EXTDQ.OB)
Coherent (COHR) www.coherentinc.com	6/01	OSRAM Opto Semiconductors/subs. Osram (Siemens, SI, sole shareholder); Rofin-Sinar (RSTI)
Cree Inc. (CREE) www.cree.com	5/01	AXT (AXTI); Nichia Corporation (pvt.); Toyoda Gosei Optoelectronics Products/Toyoda Gosei (div. 7282.BE)
Danaher Corp. (DHR) www.danaher.com	2/02	Emerson Electric (EMR); GE-Fanuc (JV GE (GE) and Fanuc Ltd. (FANUF.PK)); Mitsubishi Electric Automation/Mitsubishi Electric (div. MIELY.PK); Siemens (SI)
Emerson (EMR) www.gotoemerson.com	6/00	American Power Conversion (APCC); Marconi (MONI.L); Toshiba (TOSBF.PK)
Fairchild Semiconductor (FCS) www.fairchildsemi.com	1/01	(See Advanced Power entry.)
FLIR Systems (FLIR) www.flir.com	1/02	DRS Technologies (DRS); Raytheon Commercial Infrared/Raytheon (subs. RTN); Wescam (WSC, Canada)
Harris Corp. (HRS) www.broadcast.harris.com	9/02	AI Acrodyne (ACRO); EMCEE Broadcast Products (ECIN); Itelco (pvt.); Thales (THS.L)
Infineon (IFX) www.infineon.com	12/00	(See Advanced Power entry.)
International Rectifier (IRF) www.irf.com	4/00	(See Advanced Power entry.)
Itron (ITRI) www.itron.com	10/02	ABB (ABB); Invensys (ISYS.L); Rockwell Automation (ROK); Schlumberger Sema/Schlumberger Ltd. (SLB); Siemens (SI)
IXYS (SYXI) www.ixys.com	4/00	(See Advanced Power entry.)
Kemet Corp. (KEM) www.kemet.com	5/02	AVX Corporation/Kyocera Group (AVX); EPCOS (EPC); NEC Corporation (NIPNY); TDK Corporation (TDK); Vishay (VSH)
L-3 Communications (LLL) www.l-3.com	12/02	DRS Technologies (DRS); Integrated Defense Technologies (IDE); United Technologies (UTX)
Magnetek Inc. (MAG) www.magnetek.com	8/02	Ascom Energy Systems/Ascom (subs. ASCN, Switzerland); Astec/Emerson Electric (subs. EMR); Delta Electronics (2308, Taiwan); Tyco (TYC)
Maxwell Technologies (MXWL) www.maxwell.com	3/01	Cooper Electronic Technologies/Cooper Industries (div. CBE); NESS Capacitor/NESS Corp. (pvt.)
Microsemi (MSCC) www.microsemi.com	4/01	Semtech Corporation (SMTC); Zarlink Semiconductor (ZL)
Oceaneering Int'l. (OII) www.oceaneering.com	6/02	Alstom Schilling Robotics/ALSTOM (subs. ALS, France); Perry Slingsby Systems/Technip-Coflexip (subs. TKP); Stolt Offshore (SOSA); Subsea 7 (JV Halliburton (HAL) and DSND (DSNRF.PK))
Power-One (PWER) www.power-one.com	5/00	Artesyn Technologies (ATSN); Celestica (CLS); Lambda Electronics/Invensys (subs. ISYS.L); Tyco Electronics Power Systems/Tyco Electronics (div. TYC); Vicor (VICR)
Raytheon Co. (RTN) www.raytheon.com	10/01	BAE Systems (BA.L); Integrated Defense Technologies (IDE); Lockheed Martin (LMT); Northrop Grumman (NOC)
RF Micro Devices (RMFD) www.rfmd.com	2/03	Hitachi (HIT); Skyworks (SWKS); TriQuint Semiconductor (TQNT)
Rockwell Automation (ROK) www.rockwellautomation.com	9/01	Honeywell (HON); Invensys (ISYS.L); Mitsubishi Electric Automation/Mitsubishi Electric (div. MIELY.PK); Parker Hannifin (PH); Siemens (SI)
Sensytech (STST) www.sensystech.com	4/03	Northrop Grumman (NOC); Raytheon (RTN)
TRW Inc. (TRW)** www.trw.com	1/01	Conexant (CNXT); Fujitsu (6702, Taiwan) www.fujitsu.com, Information & Electronic Warfare Systems/BAE Systems (div. BA.L); Northrop Grumman (NOC); RF Micro Devices (RFMD); Vitesse Semiconductor (VTSS)
Veeco Instruments (VECO) www.veeco.com	7/02	Aixtron (AIX, Germany); Emcore (EMKR); FEI Company (FEIC); Riber (RIBE.LN); Thermo VG Semicon/Thermo Electron (subs. TMO)
Vishay Intertechnology (VSH) www.vishay.com	11/02	(See Advanced Power and Kemet entries.)
Wilson Greatbatch Technologies (GB) www.greatbatch.com	3/02	Eagle-Picher Industries (EGLP.PK); Ultralife Batteries (ULBI)

* Listed alphabetically; not a list of all public companies with similar or competing products; typically does not include private companies, except where they are large in both size and market share.

** Northrop Grumman and TRW announced a definitive merger agreement on July 1, 2002, in which NOC acquired TRW.

Note: This table lists technologies in the Digital Power Paradigm and representative companies in the ascendant technologies. By no means are the technologies exclusive to these companies, nor does this represent a recomended portfolio. Huber and Mills may hold positions in companies discussed in this newsletter or listed on the panel, and may provide technology assessment services for firms that have interest in the companies.