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Converging Technologies Drive Land Seismic Revolution

A number of advanced technologies–including high-speed WiFi communications, MEMS, LiDAR, heads-up display systems, GPS, GIS and grid computing–are coming together to enable step changes in onshore seismic acquisition and launch a new era of digital, full-wave seismic.

By Robert P. Peebler

STAFFORD, TX.–All technology-based industries follow a similar pattern of evolution. There are long periods where technology advances in slow increments, followed by short, but extremely important bursts in which step changes occur in both technology development and application. In many cases these bursts are enabled by technologies that are developed outside of the industry in which they are applied.

Take personal music players as an example. Until the invention of the Sony Walkman® in 1979, music could only be appreciated in a fixed location, such as a symphony hall or living room. Advances in magnetic tape recording technology and digital circuit miniaturization allowed Sony to develop the Walkman product, which became a mainstay of popular culture worldwide. Extensions were made along the way, including the move to CD-ROMs as the music storage system, but the product remained effectively unchanged for 25 years.

Then along came Apple's iPod® in 2001. The iPod is an ingenious product, one whose very existence came about because Apple founder and Chief Executive Officer Steve Jobs recognized that several enabling technologies were converging that would allow him to change the world of personal music forever. These critical technologies included data storage, power systems and data transmission.

The newly released iPod nano is equipped with 4 gigabytes of storage capacity–enough to hold 1,000 songs–on two solid-state flash memory chips, each the size of a fingernail. The iPod also has enough battery capacity to play for up to 14 hours, and the batteries are rechargeable, unlike those featured on the Walkman. Impressive as these storage and power systems are, the iPod could not have come about if data transmission rates had not increased dramatically.

Only a few years ago, the "pipe" to most homes and offices had a transmission rate of 54 kilobits a second (or less). Today, DSL, fiber and cable-based systems are 100-200 times faster, making it possible for iPod users to download their favorite songs in seconds.

The convergence of storage, power and data transmission technologies birthed the iPod and changed the music business forever, impacting both what people buy and how they buy it. Teenagers today are shopping less frequently at music stores, and instead downloading their music online from sites like iTunes and Napster. They do not buy 15 songs on a single CD, but cherry pick and download one or two of their favorites. An entire industry involving carry cases, speakers for the home and car, and other peripherals has grown up around the iPod.

While convergence technologies were critical to the iPod's success, perhaps equally important was the fact that Steve Jobs did not view the iPod as just another music player. Instead, he viewed it as a comprehensive ecosystem in which the iPod was merely one enabling device. To make the iPod a success, Jobs had to consider the entire ecosystem, including the behavior of consumers in pursuing Web-based music downloads and Apple's manufacturing and channel partners, who would prove instrumental in extending the iPod experience beyond the music player.

The Next Revolution

So how does convergence affect the seismic industry? Well, it already has. And I would argue that we are now at the early stages of the next revolution.

In the early 1970s, 24-channel seismic surveys were the norm. Since network technology was in its infancy, dedicated copper-wire pairs linked every channel to the central recording unit. Seismic acquisition systems recorded using 8-bit electronics. Microprocessors operated at slow clock speeds. And, although digital computers began to emerge in the 1970s, early systems featured only 24k of memory and punch card inputs.

During the latter part of the 1970s, the seismic industry began to experience revolutionary change. This was driven, in large part, by concurrent advances in other industries, most notably computer hardware and telecommunications. As the personal computer and telecommunications revolutions took hold, significant developments in microelectronics and networking benefited seismic recording systems.

By 1980, digital switching and other network technologies from the telecommunications industry were being routinely incorporated in seismic recording systems. The first seismic systems with distributed digital telemetry had entered the market, overcoming the "one wire-pair per channel" constraint and supporting a rapid expansion in channel count.

The PC revolution allowed digital electronics to replace analog circuits in seismic systems–a move that drove significant reductions in both cost and power consumption. The memory of acquisition systems increased, scaling to 16- and then 24-bit recording. The battle among Intel, Apple-Motorola and IBM drove quantum leaps in microprocessor clock speed, which enabled equipment manufacturers to further increase channel counts, spatial sampling density and system dynamic range, and to decrease unit size and weight per channel.

Fortunately, computing technology has kept pace with the enhancements in recording systems, advancing according to Moore's Law in all key areas: processing speed, storage, and memory. The decade of the 1980s was a golden age for mainframes featuring advanced data input systems and vector architectures. By employing multiple processors with ever-increasing clock speed, the industry was able to process large volumes of data using sophisticated techniques, including deconvolution and Kirchoff prestack migration.

Ultimately, the 3-D revolution was sealed with the advent of the interpretation workstation and visualization software, a derivative of computer-aided design (CAD) software that had been developed for the auto and aviation industries.

Within a relatively short period, the convergence of these critical enabling technologies drove drilling success rates from 30-40 to 60-70 percent, earning 3-D seismic its well-deserved reputation as the most significant technology to impact the E&P sector.

Similar to the iPod, the emergence of 3-D changed an industry forever. A number of companies that were mainstays of the 2-D era disappeared, often being consolidated into the operations of 3-D specialists who focused their technologies, field operational practices, and business models on the discontinuities and opportunities of the emerging 3-D era.

The convergence of a number of advanced technologies–including new wireless systems, MEMS, LiDAR, HUD, GPS, GIS and grid computing–are enabling revolutionary capabilities in land seismic that will fundamentally change the way seismic recording systems are designed and will launch a new era of digital, full-wave seismic.

What Has Changed?

It is interesting to reflect on land acquisition since the revolutionary days of

High-speed wireless communications technology, supported by advancements in solid-state data storage and power systems, is poised to replace the maze of "hard wire" cables used in seismic surveying. The data rates, implementation costs and power consumption of wireless transmission technologies are on steep performance trajectories that will only increase their suitability in seismic acquisition.

the 1980s and ask, "What has really changed since?" While there certainly have been changes, the developments have been more evolutionary than revolutionary. In fact, not long ago I was speaking to someone who had been in the seismic business in the 1980s, left to pursue opportunities outside the industry, and only recently returned. He commented that not much had changed in the last 20 years.

Certainly, there has been evolution. Surveys are being designed with longer offsets and wider azimuths. Channel counts have continued to increase. And we have moved to Linux-based clusters to supply computing capacity.

Curiously, however, while today's recording systems employ the most advanced Ethernet- and Internet-based networking protocols, data are still basically being sent back and forth along a wire. In general, I tend to agree with the observations of this returning son to the seismic industry: not much has changed in the last 15-20 years in the world of land imaging. While we are acquiring more data, we are acquiring it using the same basic technologies and workflows that were used in the 1980s. The industry has conformed to the constraints imposed by a legacy, cable-based acquisition architecture.

Unfortunately, today's cable-based acquisition systems are beginning to reach the limits of their capability. As a result, we need to think about a new revolution and a new convergence. It is hard to envision a future world–centered on cable-based systems–that looks dramatically different than today's. Even if computing, storage and data transmission technologies were to continue to evolve, which no doubt they will, we are pretty much running up against the wall when it comes to achieving a revolutionary breakthrough with the existing architectures of conventional land seismic systems.

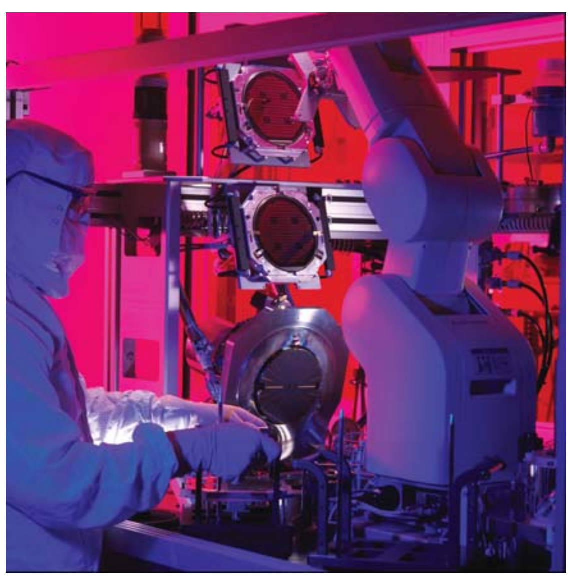
To go back to the music analogy, imagine for an instant the rack-based, home stereo system of the 1980s. It had to be plugged into the wall to obtain power. It could play 12 songs at a time off a vinyl record or cassette tape. Sound was supplied by a couple of one-meter high speakers that weighed 30 pounds or more apiece. Each unit in the system was connected to the amplifier with color-coded cables. You would never dare take such a thing with you in the car or on a plane. Now imagine the world of iPod. It still plays music, but iPod delivers it to the listener in a totally different way by capitalizing on the convergence of technology.

Are we now reaching a similar convergence point in seismic?

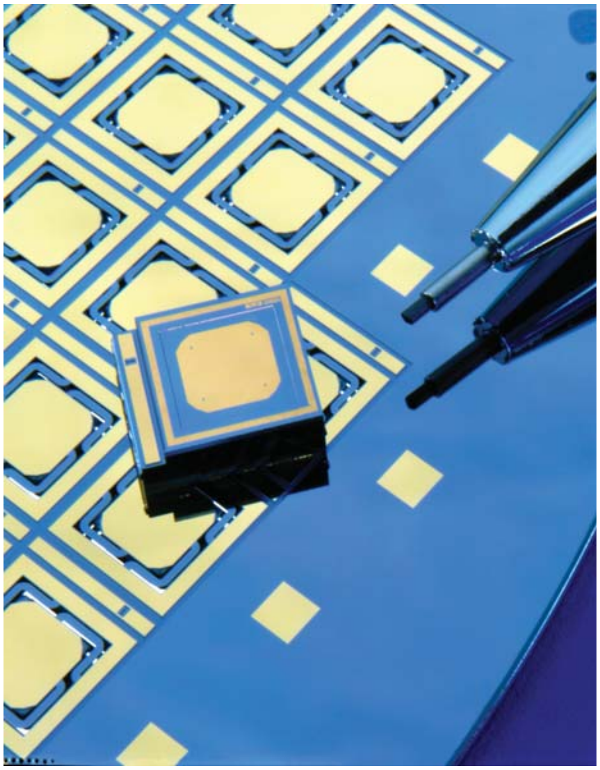
I believe there are a series of enabling technologies on the horizon that will allow us to move into another revolutionary period in land seismic acquisition. Many, but not all of these, will find their way into our industry because of technologies like the iPod, as well as from game consoles, PDAs, digital cameras, personal computers and similar electronic gadgets.

Critical Threshold

Advancements in solid-state storage technology will fundamentally change the way seismic recording systems are designed. We have reached a critical threshold in storage technology, where cost-effective data capacity is now measured in the gigabyte range. This is important in seismic acquisition since GB-level storage enables a single station to



Advances in semiconductor manufacturing have made the production of micro-electro-mechanical systems reliable and cost competitive. In seismic applications, three MEMS accelerometers in an orthogonal configuration increasingly represent the sensor of choice.



Digital three-component MEMS sensors record the full seismic wave field, including pressure, shear/converted, and surface waves, with high vector fidelity. When combined with advanced preprocessing techniques such as vector filtering, MEMS accelerometers deliver seismic data with exceptional dynamic range and bandwidth for improved imaging.

record data from the average seismic survey over a multiday period. As a result, field storage of large volumes of seismic records (at the terabyte-level across a distributed, multithousand station network) becomes economically practical and the rationale for having cables to bring data back to a central recorder becomes far less clear.

The other important function of cables in conventional land acquisition systems is to supply power. However, battery manufacturers have been investing heavily in research and development over the past several years given increasing demands for autonomous, highly efficient power systems. Cell phones, laptop and notebook computers, digital cameras, personal game players, and a myriad other consumer electronics products continue to drive demand. The emergence of electric cars adds further fuel to the interest and the collective investments being made in power systems.

Lithium ion (Li-ion) batteries comprise one of the fastest growing segments in power systems, finding application in areas where energy density and weight are of prime importance. These batteries offer fast recharge times, longer supply windows between recharges, an increased number of charge/discharge cycles, and a wider operating temperature range–all features that are needed for seismic acquisition systems. As with data storage systems, Li-ion battery chemistry may be close to reaching the tipping point of performance and cost effectiveness for seismic application.

Together, the convergence of solid-state storage and power system technologies will allow seismic equipment manufacturers to fundamentally rethink the architecture of field recording systems. If we can remove the cables and move to single-station recording systems, we will be able to eliminate the challenge of having a serially dependent network in which one fault brings down the entire system. In addition to improving the reliability of the seismic network, cableless recording systems will deliver substantial benefits to seismic contractors in the areas of logistics and field productivity, as well as health, safety and environmental.

E&P operators will capture these benefits along with the flexibility to design customized, high station-count surveys that fully sample reflected seismic energy without aliasing (or distortion). Surveys that record with 20,000 or more live stations will be increasingly common. As a result, image quality should improve significantly.

Enabling Technologies

To transmit data from solid-state storage in the field station units to portable data collectors, seismic systems will take advantage of the latest wireless technologies, such as 802.11 (WiFi). The original WiFi protocols hit the market in 1997, driven by requirements from all sorts of wireless products, including mobile phones, laptop computers and PDAs. The original WiFi standard targeted data transmission rates of 1-2 megabits a second. Current extensions of 802.11 are under development, which will increase transmission rates to 500 megabits/second within the next few years. The data rates, implementation costs, and power consumption of all wireless transmission technologies are on steep performance trajectories that will only increase their suitability for seismic acquisition.

Concurrently, advances in semiconductor manufacturing have made the production of micro-electro-mechanical systems (MEMS) chips reliable and cost competitive. In seismic applications, three MEMS accelerometers in an orthogonal configuration are increasingly being acknowledged as the sensor of choice by geophysicists. Digital three-component MEMS sensors record the full seismic wave field (including pressure, shear/converted, and surface waves) with high vector fidelity. When combined with advanced preprocessing techniques like vector filtering, MEMS accelerometers deliver seismic data with exceptional dynamic range and bandwidth. Noise can be recorded and eliminated mathematically, rather than filtered mechanically using geophone arrays. The end result is improved seismic image quality and utility (which is further enhanced when the energy is fully sampled).

Recording systems and sensors will not be the only areas impacted by converging technologies. Field operations, processing and interpretation will be affected as well. In the field, we expect to see greater use of light detection and ranging (LiDAR), global positioning systems (GPS), and heads-up display (HUD) technologies. LiDAR, GPS and HUD systems will be tightly integrated into survey design and field acquisition processes, improving the productivity, accuracy and HSE risk profiles of the seismic operation.

Today's seismic survey operation consists of a crew manually marking shot points and receiver and line locations with flags, stakes and biodegradable paint. Unfortunately, significant delays are often experienced between surveying and acquisition, which allows weather, animals and human interference to degrade the survey preparations. While one could attempt a "quick and dirty" resurvey using off-the-shelf GPS units, the majority of commercial units today only have an accuracy of ±30 meters, a tolerance that is probably insufficient for the majority of seismic applications.

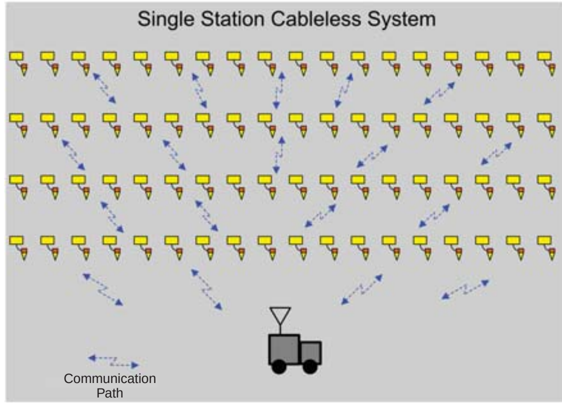
Whatever the technique, and even if the survey markings did not degrade, there is always the potential for human error in placing the receiver array or positioning the sources, since the primary "navigation tool" in land acquisition today is still a paper map.

LiDAR and heads-up display technologies promise to change the world of seismic surveying and field operations. LiDAR is actually a portfolio of technologies derived from the aerospace, defense and agriculture industries, in which a digital elevation model (DEM) is output with the intent of accurately mapping the topography of a given environment. The DEM becomes a significant input into a comprehensive geographic information system (GIS), which helps integrate and display geographically referenced information in a digitized, computerized format.

The DEM can then be integrated with other data sets including vegetation and urbanization models (in which landscapes, both natural and man-made, are overlaid). This creates a real-life look for the targeted acquisition area that can be visualized in three dimensions with the appropriate planning and navigation tools in the office and doghouse and, with the use of HUD technology, in the field.

HUD has already gained significant traction in military applications, including in advanced fighter aircraft, and increasingly, among the infantry. It is also being increasingly used in the medical industry, helping surgeons to view an overlay of an x-ray or other scanned image over the normal view of a patient, or to quickly reference manuals and patient files.

Existing HUD systems project images onto a fixed, clear optical glass element that is located in front of the eye. The latest systems are based on micro-display technologies and mount the HUD on the user's visor, allowing the image to be viewed over the entire angular area through which the user can move his head. Projection for visor-mounted systems is done by means of a tiny head-mounted projector and lens



Solid-state storage and power system technologies are allowing next-generation field recording system architectures. Cableless recording systems promise improved reliability, logistics and field productivities, as well as health, safety and environmental benefits. Shown here is an example layout of a cableless land data acquisition system.

arrangement, which increases functionality and portability while reducing weight. Early development and testing of LiDAR and HUD applications are already underway within the seismic industry.

Whole Different World

One can imagine a world in the not-too-distant future where the approaches to surveying and acquisition change dramatically. The stakes, flags and paper maps would disappear, as would the time lag between survey and acquisition operations. Instead, acquisition crews would have access to digitized, computerized maps in three dimensions, in the field, on a real-time basis. These maps would outline all shot and receiver points and be projected to them live using HUD technology.

The increased use of accurate, digitized survey information, complemented by the increased use of next-generation GPS systems in single-station recording systems and on sources, should eliminate much of the cycle time associated with seismic data reprocessing and correcting geometry errors.

On the processing front, we will certainly see ongoing enhancements to microprocessor clock speed and data storage and transmission capacity. Parallel processing using cluster technology will still be the primary computational architecture for the next decade or two, but the concept of grid computing will likely gain increasing acceptance. The first implementation of parallel processing happened within a single box: the high-end mainframe. The second implementation took place across a cluster of multiple boxes, but within a single computer center. Round three is likely to involve simultaneous processing across multiple centers, allowing oil and gas companies, seismic processors and third-party providers to share their computational capacity across a distributed grid. IBM has been leading the charge in this area, but others will surely follow (or perhaps even capture the leadership position themselves).

The seismic industry will need this increased computing capacity to handle the explosion in data that is likely to take place, as land surveys move to three channels per station (to record full-wave 3-C data) and station counts expand to 20,000 (or more) from the typical 3,000 stations of today. The increased compute capacity will not only allow the industry to manage the greater data load, but also to apply a broader array of increasingly sophisticated algorithms to the data. Prestack depth migration (both Kirchoff and wave equation) will become more common for onshore prospects, while the industry will be able to apply the next generation of migration algorithms like reverse time migration.

The onshore seismic imaging world of the future will look very different from the world of today. We will take advantage of technology developments in data storage, power and data transmission technologies to get rid of the cables and architect single-station recording systems. We will be taking more and better measurements, supported by the deployment of tens of thousands of digital 3-C sensors that fully sample the full wavefield of reflected seismic energy.

The seismic industry will adapt its survey planning and field acquisition methods to take advantage of these new recording systems, and modify its workflows to better capture the benefits LiDAR, GPS and HUD will make possible in operational productivity and HSE performance. Data will flow seamlessly and without geometry errors into processing, where ever-expanding compute capacity allows more data to be processed with more complex and accurate algorithms.

We can debate whether these changes are evolutionary or revolutionary. From my perspective, the seismic industry is at another convergence point and is about to embark on a revolutionary journey into the next era of digital, full-wave seismic. I am hopeful that within another 10 years, when I speak with that recently returned colleague, he will finally admit that the world of land imaging is nothing like the one he recalls from the 1980s. ❒

ROBERT P. PEEBLER

Robert P. Peebler has been president and chief executive officer of Input/Output Inc. since April 2003, and a member of its board of directors since 1999. Before joining Input/Output on a full-time basis, Peebler was the founder, president and CEO of Energy Virtual Partners, an asset development and management company for oil and gas properties. Before that he served as vice president of e-business strategy and ventures at the Halliburton Company. Peebler joined Halliburton in 1998 when it acquired Landmark Graphics, where he had been CEO since 1992. He began his career with Schlumberger in wireline operations, and spent 17 years in various positions with the company, including head of U.S. wireline operations and executive in charge of strategic marketing for the corporate energy services group. Peebler holds a B.S. in electrical engineering from the University of Kansas.