Making dumb places smart is what wearable computing is really about,” says Edward McConaghay, president and chief executive officer of ViA Inc. (www.via-pc.com)—“and bringing knowledge to knowledge workers in the field can provide high returns on investment.” For proof, McConaghay points to the use of connected wearables that let technicians work on expensive capital equipment without running back and forth to distant terminals for critical technical data. Those efficiencies can save labor hours for deployments in shipbuilding and commercial aircraft inspection, while also reducing construction and maintenance times for these large capital projects.

As one example, McConaghay cites Bath Iron Works (BIW), a shipbuilder in Bath, Maine, that used ViA's shipyard inspection application to realize an 80-to-1 return on investment over a three-year amortization period. That 8,000-percent return resulted from 70-percent reductions in inspection times, created because connected wearables reduced average information delivery times from two or three hours to about 20 minutes. Reconciliation of design versus the as-built systems and speeding design remediation are also key areas that can yield a high ROI.

Motivated by these labor savings and associated schedule efficiencies for their large capital projects, capital-intensive industries are often early adopters of wearable computers. (See the “Early Work” sidebar for a discussion of pioneering experiments in wearable computing and augmented reality at Boeing.)

FORM FACTORS AND ENTERPRISE CONNECTIVITY

For these wearable applications, McConaghay found that physical form factors and interface technologies play a crucial role. There is such a thing as too small, his customers told him. For example, they found the PDA-style QVGA displays inadequate for many applications. The small PDA screens show diagrams or map details out of context or else give the big picture without readable detail. Both are unsatisfactory for users who need detailed design data. Inadequate resolution even forced some customer organizations to reject VGA displays.

Six- to eight-inch tablet-style color displays, with 800 × 600 SVGA resolution, provide a workable middle ground for wearable computers in industrial applications. This size screen will display design drawings, schematics, and documentation in a useful context. Screens larger than eight inches are not casually portable, while those smaller than six inches are not easily readable or lack resolution for the design data industrial knowledge workers need to function effectively.

Also, having separate displays, computing cores, and peripherals in wearable configurations lets industrial users customize system capabilities to meet the demands of the various environmental constraints they face. For example, indoor- or outdoor-readable displays can be configured, depending on the application, with the same core and port connectors. Figure 1 shows the tool belt form factor that ViA offers for industrial workplaces. Figure 2 shows a closeup of the central computer unit.

Plans to use the increasingly capable PDA cores for wearables might not pan out, according to McConaghay. Not only are small displays a problem, but there is such a thing as too little functional capability. Most PDA operating systems simply don’t offer enough system services and application support. Moreover, as the PC architecture be-
ViA products use low-power Transmeta Crusoe processors, with up to 128 Mbytes of RAM and multigigabyte local hard drives, but they still offer long battery life. Batteries operate in pairs for extended operation and allow hot swapping. Local gigabyte hard drives reduce bandwidth requirements during day-to-day operations, reducing load on heavily used wireless LANs. The systems also offer a full range of ports and peripheral support, including USB, serial ports, FireWire, and PCMCIA, which allow hard connections to equipment in the field.

Wireless connectivity, predominantly IEEE 802.11, lets wearable computer...
**Wireless Infrastructure Matters**

Northwest Airlines, with operations making it the fourth-largest airline worldwide, runs an extensive aircraft maintenance operation. According to Chuck Layton, formerly a business specialist with Northwest’s Technical Operations Systems group, a Boeing 747 will require over 4,000 scheduled upgrades, replacements, and repairs during a major maintenance cycle. Also, about 4,000 additional problems discovered during rigorous inspections must be tracked and repaired. These can range from aircraft safety issues to cosmetic ones like torn upholstery, scratched paint, or chewing gum.

These maintenance checks can take 15 to 45 days, with nonroutine maintenance accounting for about half of that. The old nonroutine maintenance process used paper forms in triplicate to track the problems. Copies went to the work control center, to lead mechanics for evaluation and identification of needed repairs, and to working mechanics, who performed the repairs.

To reduce nonroutine maintenance times, Northwest evaluated wearable computer systems for its inspectors and lead mechanics, the most mobile 10 percent of the inspection and maintenance workforce. According to Layton, Northwest considered several pen-based devices, but most ran low-function PDA operating systems that could not interface to the enterprise database systems, run the necessary applications, or deliver the power requirements necessary for 802.11 RF transmitters. Northwest also rejected PDAs because of inadequate screen real estate and found tablets and laptops inappropriate for their inspectors’ hands-busy environment.

ViaAs tool belt form factor let inspectors work using mirrors, flashlights, and other tools, only using the wearable to record their conclusions. The wearable thus became one highly effective tool among the several needed to get the job done. Inspectors like the hands-free portability, Layton found, because they work in tight spaces and can’t set down traditional laptops. They also like to touch the screen display and value its ability to withstand rough handling. The dual battery system also gives mechanics time to complete their maintenance checks.

The Pentium-compatible Transmeta Crusoe-based wearables interface with Northwest’s enterprise databases through standard PC-based applications, so inspectors could use the same databases as on their desktops. Northwest added custom database software with templates for the most common inspection tasks, a bar code reader, and a PCMCIA wireless LAN card to transmit information to the maintenance databases. Entering information to the database allows real-time consistency edits, improves security, and avoids errors associated with handwritten paper forms.

After a successful test roll-out on 757s, the system was scaled up for deployment in the much larger 747 maintenance hangar. This ramp-up required deploying multiple 802.11b access points to get coverage across the entire hangar floor—and even inside the aircraft during the inspections. Northwest had to resolve significant system administration issues before the access points were properly coordinated, which caused some acceptance issues in spite of good performance of the wearable systems themselves.

In industrial settings such as maintenance hangars, the environment can be dynamic: moving scaffolds or aircraft can change the coverage patterns. Also, prospective users should evaluate the degree of redundancy required to avoid loss of coverage from a single access point failure and consider using repeaters for difficult coverage areas. Portable repeaters can be especially valuable in a dynamic environment where dropout zones can change.

Layton also suggests that prospective users identify any controlling authority for local wireless networks, such as the Metropolitan Airport Council at the Minneapolis–Saint Paul Airport in his application, regarding transmitter power, frequency ranges, and protocols. If an existing network must be used, its uptime performance and available bandwidth might or might not suit a particular user’s business goals.

**What Makes for Successful Deployments?**

Most successful wearable computing deployments fit the technology into existing work processes, according to McConaghay, reducing wasted time by getting information directly to knowledge workers without them leaving the work site. By contrast, system implementations requiring major workflow redesigns, which force workers to adapt to the technology rather than adapting the technology to them, are more likely to fail.

Involving the user communities early is important, McConaghay stresses; their input on the workflow plays a critical role in designing efficiency-producing information systems. A successful wearable computing deployment will have prospective users identify processes that require high information and knowledge content. Once these processes have been identified, wearable computers can be deployed to deliver information flow tailored to optimize physical workflow, avoiding unnecessary disruptions.

Because wearable computers are always carried by their users, they can be applied to real-time computing in mobile, walk-around environments. As users access corporate databases, containing detailed plans, drawings, and documentation, when inspecting or repairing complex technical equipment. It also facilitates project management and delivers special expertise to the on-site worker using teleconference software such as CUseeMe or NetMeeting. Voice-over-IP is an available option, but requires design attention to guarantee optimal quality of service, possibly even dedicating a separate 802.11 network to voice. Otherwise the data packets sharing the VoIP LAN might disrupt the continuous voice packet stream.

Smooth functioning of wireless connectivity in industrial environments can strongly affect the acceptance of wearables, as the “Wireless Infrastructure Matters” sidebar discusses in describing the nonroutine-maintenance system at Northwest Airlines.
Xybernaut supports a variety of form factors and system software

Founded in 1990, Xybernaut (www.xybernaut.com) has developed and commercialized wearable computer hardware and software design. It produces devices and systems specialized for workers who need mobility, portability, and hands-free operation. Xybernaut wearables present audio-visual interfaces and compatibility with various operating systems. Visual content can be delivered to the wearer without interfering with the full range of vision using head-worn displays.

These wearables offer enterprise-LAN connectivity, voice navigation, and wireless communications, on an Intel platform. They are body-worn and voice-activated, and have modern processors, with color flat-panel or head-mounted color displays, microphones, and eyepiece displays. They support microphones for speech recognition and aural feedback.

Figure B shows a Xybernaut Mobile Assistant, Transferrable Core wearable system with a detachable interface module that supports a wide range of analog and digital connections, including USB, FireWire IEEE1394, Serial RS 232, S video, PS2, SVHS, and audio and video ports.

Figure C shows the wearable Xybernaut poma system, which offers email, Internet browsing, or games, and an integrated MP3 player. The three-ounce, one-inch color, 640 × 480 VGA viewing screen gives a view similar to that of a desktop monitor from two feet away. It runs Microsoft Windows CE on a 128-MHz RISC processor, with 32 Mbytes of RAM, 32 Mbytes of ROM, a compact flash slot, and a USB port. It supports 1-Gbyte microdrives, a wireless modem, and LANs in a compact flash slot. The USB port connects to a handheld mouse. Wearable keyboards and other pointing and input devices can also be added.

Figure C. The Xybernaut compact poma wearable information appliance provides heads-up display at full VGA resolution.

Figure B. The Xybernaut MA TC with a removable input/output module that lets workers interface the wearable to a wide range of peripherals and equipment in the work environment.

Full-function computers, wearables of this class work equally well whether connected to the network or not and don’t need regular synchronization, even while continuing to provide the design documents and data users need to work effectively. Also, they can run existing applications already available on desktops and servers.

For these reasons, McConaghay’s ViA wearable systems represent an emerging product category with desirable features such as low weight, portability, high-bandwidth connectivity, adequate battery life, and PC-compatible computing. For that, prospective wearable users must identify processes that require high information and knowledge content.

Wearable at BIW’s shipyard

On the application side, BIW has a rapidly increasing portfolio of systems that use wearable computing platforms, including

- Virtual test equipment system: A test kit providing oscilloscope and multimeter functions that uses physical data ports on the wearable PC to interface to shipboard systems, which use the wearable system to display, format, and record readings
- Virtual maintenance system: A communication system that sends voice, video, and still images of various resolutions to remote experts and displays Interactive Electronic Technical Manuals, a DoD XML/SGML-based standard for electronic system documentation, directly to workers
- Gatekeeper access control: A wearable system for guards managing
physical security at gates and other facilities providing alerts and communication capabilities

- **Wearable firefighting ensemble:** A damage control software system wrapped up into a compact wearable computer that fits comfortably under an insulated fire suit, with a low-light camera, an RF locator system, and a wireless LAN

- **Shipboard wearable nonlethal acoustic defense system:** A system using active beam-forming, capable of translating into numerous languages and transmitting warnings or nonlethal but disorienting acoustic energy to potentially hostile small craft as they approach larger ships

“This is a shipyard, we bend steel here,” Vince Quintana of the BIW mobile information systems group says in describing BIW’s rugged industrial environment. Operating where large unfinished steel structures are shaped and con-

In providing insight on how research analysts view the emerging wearables market, Venture Development Corporation’s (www.vdc-corp.com) Tim Shea notes that wearables accounted for over US$70 million in revenue to suppliers in 2001. VDC recently surveyed 500 organizations that are current or prospective users of wearable computers. In summarizing that work, Shea’s report, “The Global Market for Wearable Computers: The Quest for Killer Applications” (www.vdc-corp.com/industrial/reports/02/br02-03.html), assesses the wearable market in terms of system form factors, industry applications, operating systems, input devices, wireless networking, and leading vendors.

On the basis of plans these respondents report, VDC projects a market growth of between 20 and 50 percent per year through 2006. Shea believes that industrial applications of the type this article discusses will drive this growth initially, enabled by product and infrastructure improvements including continuing miniaturization, increasingly functional wearable systems, head-mounted and eyewear displays, wireless LAN and WAN communications protocols, and improved multimodal interface technologies such as handwriting, speech recognition, and speaker identification. Shea’s report identified belt and head-worn systems, along with wrist- or finger-worn barcode scanners, as the form factors having the largest share of today’s market.

Major industrial applications include equipment maintenance (airline or shipyard inspections), queue service delivery (fast food or airport lines), distribution (product picking, packing, delivery, and inventory tracking), retail (stock and inventory management), field service (telecommunication network maintenance and repair), and military (integrated logistics support, vehicle and aircraft maintenance).

Shea expects different wearable devices to emerge that cluster capabilities by market segment. For example, a converged multimodal device with an advanced WAN for voice and data capabilities, organizer and scheduler applications, and voice dialing, for interactive shopping, directions, ticket buying, or stock trading, might serve one end-user community. By contrast, warehouse devices require a different function cluster, including a wearable bar code scanner, audio output, and voice data input, for picking, packing, or sorting instructions, residing in a holster-based handheld. Enterprise database connectivity is also required, probably using high-bandwidth industrial wireless LANs.

Shea identified the following prominent market players:

- **Charmed Technology (www.charmed.com):** Los Angeles-based MIT Media Lab spin-off developing affordable, wearable Internet products, services, and technologies.
- **Psion Teklogix (www.psionteklogix.com):** Provides mobile wireless devices and access to mission critical enterprise IT systems. Specializes in solutions for warehousing, distribution, transportation, logistics, and mobile computing.
- **Symbol Technologies (www.symbol.com):** Provides a variety of industrial handheld and wearable pervasive devices (see the July–September issue of this department for more details).
- **ViA (www.via-pc.com):** Provides a wearable computer line and custom software development support for applications in inspection, maintenance, quality control, supply chain management, and security.
- **Vocollect (www.vocollect.com):** Provides voice entry technology to support multimodal user interfaces in wearable and pervasive devices including its Talkman product.
- **Xybernaut (www.xybernaut.com):** Conducts R&D and commercialization of wearable computer technology hardware and software design, specializing in mobility, portability, and hands-free operation.
structed, a wearable must resist impacts with hard surfaces and work under a variety of environmental conditions having a range of temperature extremes. Quintana’s group also needs at least eight hours of battery life for a full working shift: going for fresh batteries is just as wasteful of valuable knowledge-worker time as going to get design data.

In industrial settings, wireless networking is another crucial issue. Shipyard installations require careful design because of their large masses of ferrous metal that block RF transmission (see Figure 3). BIW conducted accurate site surveys to guarantee good coverage and deploy multiple access points.

Beyond its shipyard deployment at BIW, ViA has developed a range of applications that include agricultural data collection systems, a wearable ensemble for shipboard firefighters, a shipyard inspection support system, mobile-agent check-in airport terminals, a nonscheduled-aircraft-maintenance system, and construction and excavation site surveys. Other wearable computing vendors such as Symbol Technologies and Xybernaut have developed their own diverse range of applications (see the “Xybernaut Supports a Variety of Form Factors and System Software” sidebar on page 17 and the “Assessing the Wearable Computer Market” sidebar on page 18). These deployments involve a range of diverse user requirements. Wearables need to be mobile, portable, comfortable, and reasonably lightweight. For example, a tool belt form factor fits well in industrial applications, because industrial workers sometimes want hands-free operation, which can require speech recognition.

At ViA, user interface options are kept open by the modularity of a user’s wearable systems, letting the user customize his or her systems for tasks particular to each application. Touch screens with pen input are used most often; the displays can be transmissive for indoor use or reflective for outdoor use under direct sunlight.

Speech recognition is another option, but McConaghay cautioned that it needs careful design for command and control, forms fill-in, or dictation, depending on the application. Moreover, industrial environments often require noise cancellation microphones. Other desirable attributes include ruggedness, heat and cold resistance, and readable screen sizes. Figure 4 shows wearables in Antarctica and at a local coffee shop, demonstrating that this computer form factor is on its way to becoming, well, pervasive.

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**Pervasive Computing Puts Food on the Table**

We interview Action Systems Inc. CEO Alex Malison, who is developing restaurant order entry and management systems using wireless pervasive palmtops at table side. He told us that the venerable order pad is a tough and reliable competitor, but palmtops transmit orders directly to the kitchen to avoid transcription errors and save waiters many round-trips. Results: customers are served fewer wrong orders, get faster service, and are happier. He describes experience with system architectures, and design of flexible user interfaces with handwriting recognition.