The Evolution of Army Wearable Computers

In 1989, the US Army envisioned a small wearable computer to assist soldiers with battlefield tasks. The concept has since grown from preliminary prototypes and a demonstration Soldier's Computer into the current Land Warrior program and proposals for future systems.

Matthew J. Zieniewicz, Douglas C. Johnson, Douglas C. Wong, and John D. Flatt
Research, Development, and Engineering Center, US Army Communications Electronic Command

Wearable computers will soon become a reality on the battlefield for frontline troops, under the US Army's Land Warrior program. Here, we trace the evolution of Army wearable computers, from the initial concept and first prototype, through downsizing and improvements, to future product directions. We focus on two major programs central to the Army's development of wearable computers: the Soldier Integrated Protective Ensemble (SIPE) and the Land Warrior system. As the Land Warrior program nears fruition, the Army continues to advance the state of the art for wearable battlefield computers.

Early beginnings: The Soldier's Computer

The history of Army wearable computers has its roots in 1989 with James Schoening, a research analyst working at the US Army Communications Electronics Command (CECOM), Research Development and Engineering Center (RDEC). (See the "Glossary" sidebar for terms used in this article.) Schoening envisioned a small wearable computer, integrated with a wireless link and helmet-mounted display (HMD), that could help individual soldiers on the frontline. Working with Matt Zieniewicz, Schoening transformed his idea into a system architecture with targeted technologies, such as wireless data transmission, image capture, integrated Global Positioning System (GPS) receivers, and menu-driven software.

In 1990, Schoening and Zieniewicz teamed up with John Flatt, Sal Barone, and Almon Gillette to demonstrate an early surrogate system, the Soldier's Computer, at the Army Material Command's first trade show in Aberdeen, Maryland (see Figure 1). The Soldier's Computer employed an Agilis brick-type 386-based computer with an integrated packet radio system, which soldiers could load into their backpacks. The system was relatively lightweight for the time, at approximately 10 pounds. It also included software for creating reports and displaying battlefield situation maps.

In addition, a serial interface to an external GPS receiver let soldiers see their position on a map. The map was displayed on a ruggedized (metal case) helmet-mounted quasi-VGA (720 × 280) display (Reflection Technologies' Private Eye display). It used a vibrating mirror and red LEDs to compose a virtual 14-inch monochromatic (red-on-black) display. Soldiers used a trackball for input and could enter and transmit simple reports to other units.

The system was a resounding success in demonstrations to senior Army leaders and congressional staff members.

The next iteration of the Soldier's Computer shifted from a proprietary brick design to an open system–bus wearable design. The Natick Soldier Center in Massachusetts incorporated this concept as a key component of its SIPE Advanced-Technology

Demonstration. The SIPE project, led by Carol Fitzgerald, was the first time the Army treated the various combat equipment components for the individual soldier as one integrated system rather than as a conglomeration of individual components (SIPE also included other advanced components in the areas of the fighting uniform, load-bearing equipment, weaponry, and thermal imaging).[1]

The prototype design for the SIPE project began in earnest in the spring of 1990. At that time, wearable computers were in their infancy. Steve Mann at MIT had produced some early wearable computers,[2] and during the summer of 1991, Carnegie Mellon University developed its VuMan project,[3] but the SIPE computer approach differed from the typical research project. As part of a new digitized battlefield concept, it aimed to implement desired battlefield functions through technical means rather than explore an advanced technology and then develop an application for it. This key difference influenced the entire design process.

The design team (see the "Soldier's Computer Design Team" sidebar) had to develop features (such as video capture) that could operate in a rugged environment. In simulated war-game exercises, actual soldiers planned to test the system (10 prototypes) over several weeks in various outdoor environments and during live-fire exercises. With this in mind from the outset, the design team aimed to develop a portable, wearable battery-powered computer with suitable battlefield applications software. The computer needed to include image capture, an integrated radio for transmitting data between soldiers, and a portable display unit, preferably helmet mounted. The time frame for developing the system was 24 months, with the last three months reserved for field testing and demonstrations. The budget for the computer-radio-GPS portion (exclusive of the helmet display unit) was US$500,000, including all labor, materials, software development, and prototype construction.

Glossary

C4ISR	Communications, command and control, computing, intelligence, sensors, and reconnaissance
CECOM	Communications Electronics Command
HMD	Helmet-mounted display
IPT	Integrated process teams
JCF AWE	Joint Contingency Force Army Warfighting Experiment
MDSE	Mission Data Support Equipment
ORD	Operational Requirements Document
RDEC	Research Development and Engineering Center
SIPE	Soldier Integrated Protective Ensemble
TWS	Thermal Weapon Sight
WSS	Weapon subsystem

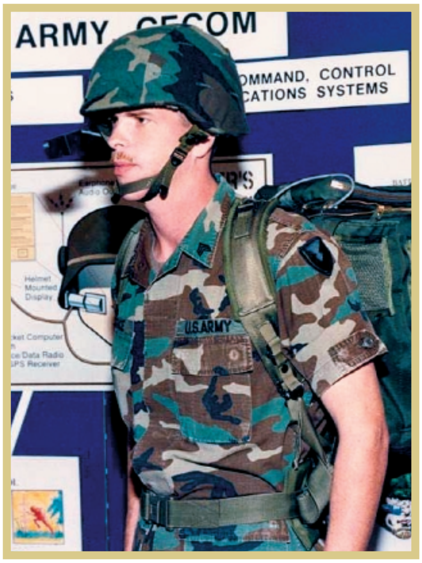

Figure 1. The Soldier's Computer at the Army Material Command's first trade show in 1990. Note the small helmet-mounted VGA display. The visible cord is the VGA feed from the computer to the display. The military still uses this monocular concept in an improved form. (The small stub antenna for the integrated spread-spectrum packet radio is not visible.)

Functionality and requirements

Because this was the Army's first attempt to bring computing devices to the individual soldier, there were no preset system requirements, and users did not have specific functions in mind. Initial brainstorming with the Infantry School—led by the system's software engineer, William Sanchez—developed key desired functions (listed in the next paragraph). At the time, none of the functions were commercially available in portable computers, but most were available through various stand-alone electronic or computer components. The challenge was to integrate these piecemeal components into a lightweight package that could

Soldier's Computer Design Team

Numerous engineers lent their support throughout the Soldier's Computer effort, but certain key personnel ensured the success of developing the computer-radio-GPS system. The core technical team members were Matt Zieniewicz, project leader, system architect, and video capture and compression specialist; William Sanchez, chief applications development software engineer; John Flatt, networking and communications engineer; James Wright, project leader; Almon Gillette, packaging, electrical, and mechanical interfaces; and Eric Hall, networking. In addition, Carl Klatsky provided valuable assistance during the final prototype construction and system checkout phase, and James Schoening continued to work with the Infanty School on requirements; his guidance and insight were essential throughout the project to develop system concepts.

achieve the desired result without being too bulky and cumbersome or requiring too much power. The team decided early on to evaluate the best commercial components in each area (video capture, GPS, data communications, networking software, storage media, operating systems, programming languages, bus interfaces, and processor boards) and then make trade-offs to arrive at the best possible system architecture. They incorporated the functionally derived hardware requirements in a custom housing, developed within RDEC's drafting, design, and fabrication division.

The new system aimed to digitize basic battlefield operations to help soldiers

- Read maps, navigate, and maintain situation awareness (so they could ask, for example, "Where am I, where are my squad members, and in which direction am I heading?")
- Receive, prepare, and send written field reports (so they could, for example, send a call for fire or an operational order, or prepare spot reports or Frago orders—written military reports used by frontline troops)
- Capture and transmit color still images for reconnaissance purposes
- Access battlefield operations reference material (such as silhouettes of enemy fighting vehicles, first-aid procedures, common battlefield tasks, and standard procedures)

These functions were the basis for the software application, developed in C. The team developed other functions as separate modules and included them in the main program to provide modularity and ease of testing. They also designed screens and screen layouts from scratch, using input from the Infantry School, the Army Human Engineering Laboratory, and Natick engineers and project leaders. Fortunately, the initial software's functionality proved very useful, and in fact, the Army later used it as the basis for the Land Warrior production systems.

System architecture

To satisfy the functionality required for the Soldier's Computer and its electronics subsystem, the system team included the following key hardware components: a computer processor with memory, a GPS receiver, a data radio, a video capture system, a digital compass, a miniature color camera, a video controller subsystem, an HMD, a power supply subsystem, wiring harnesses, and packaging (for more information, see the "Hardware for the Soldier's Computer" sidebar). From a software perspective, it was decided that it was best to create one main application program that could launch all the required functions through subprograms (see the "Software for the Soldier's Computer" sidebar). On the basis of this design approach, the project leader divided the software development into task areas and assigned them to appropriate specific project personnel.

The team then embarked on designing the first custom Army wearable computer to be demonstrated under field conditions. In effect, the team became a custom PC clone manufacturer with a limited production run. They carefully designed the system by leveraging and integrating the latest hardware components and technology available and incorporating the best software practices, programming languages, and networking techniques.

Networking configuration

The individual Soldier Computers sent the soldiers' current positions in one-minute intervals, along with digital reports and captured still images, to a central gateway unit over an FM packet radio with a range of up to one mile. At this fixed-gateway base station, messages were relayed (between two fixed, not mobile, stations) to the Novell server over a wireless link using a wireless LAN card. The soldiers used the FM radio because it offered an increased range over a wireless LAN system, and the packet mode better compensated for intermittent connectivity. (LANs did not operate well under intermittent conditions at that time, owing to the networking technology's limitations.) During a data transmission, messages were relayed from the individual Soldier's Computer to the gateway unit, to the server, and then back to the gateway for transmission to the appropriate Soldier's Computer. Despite the apparent multihop lag, soldiers did not notice any degradation in service or time delay.

Feedback from soldiers

In the fall of 1992, the Soldier's Computer was a key device demonstrated at Fort Benning, Georgia, as part of SIPE (see Figure 2). This was the Army's first attempt at "digitizing" the individual soldier, and the soldiers who used the system were impressed.

The software functionality that the system provided proved to be an asset under simulated battlefield scenarios. By feeding the imagery from the bore-sighted Thermal Weapon Sight (TWS) to the helmet display, the soldiers could fire around corners or out of foxholes, exposing only their hands and forearms to enemy fire. This feature received rave reviews from the user community.

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However, although the system enhanced the soldier's fighting capability, it needed to be more compact and operate longer on a set of batteries before it would be battlefield ready. More importantly, it needed to be lighter. The backpack-sized computer-radio-GPS unit weighed 18 pounds, and the HMD integrated into the fighting helmet tipped the scale at nearly eight pounds, with an additional 15 pounds for the high-voltage supply unit to drive the cathode ray tube-based display. Another drawback was

Figure 2. Testing and aligning the SIPE helmet display with the Soldier's Computer in July 1992. The visor reduced ambient light and was a flip-up, flip-down display. It also provided ballistic and laser protection. The right-mounted sensor on the helmet's top was an image intensifier for night vision capabilities. The large brown case is the computer-radio-GPS unit.

the delay in capturing and sending a still video image. Owing to the limited processing speeds on the video capture board and communications channel capacity (9,600 bps), capturing and transmitting images could take 45 to 75 seconds, during which time soldiers couldn't use the system for other operations.

The next phase

The Natick Soldier Center completed its SIPE project in two and a half years, and the Army's Chief of Staff was enthusiastic about furthering efforts to field an integrated fighting system with a wearable computer-radio-GPS unit. The Army also continued exploring digitized components for the individual soldier under various programs. For example, the Twenty-First Century Land Warrior project examined advanced computing and electronic products and concepts. Also, the

Hardware for the Soldier's Computer

To achieve the design requirements of the Soldier's Computer, the design team integrated several hardware components (see Figure A). They aimed to develop one main application program that would control all hardware components and peripherals—they didn't want to launch the components from separate applications. This restriction influenced their choice for many of the components, and they selected devices that provided well-defined APIs and C libraries.

The central component was a 16-bit ISA-based single-board computer consisting of a 20-MHz Intel 386SX microprocessor, with a 387 coprocessor and 16 Mbytes of RAM. The system used a passive backplane architecture with an ISA bus structure. The single-board computer plugged into the passive-backplane card. This approach made the system modular and easy to upgrade, and, most importantly, gave it the desired physical footprint. A motherboard approach would have resulted in a large rectangular board with expansion boards inserted at 90-degree angles. Employing a passive backplane allowed the cards to be stacked longitudinally alongside each other, resulting in a denser package overall.

Location functionality

To achieve the required location functionality, the design team added an ISA-type Global Positioning System receiver card (developed in 1990). They selected a NavStar model because an API library existed to provide low-level interfaces to the GPS data. This device also provided the best accuracy at that time by providing the most channels. The antenna was a puck-type antenna mounted externally at the top of the soldier's backpack frame.

Data transmission

The team incorporated a 2-Watt FM packet radio transmitter, also in a 16-bit ISA form factor, to achieve the required data transmission. For similar reasons, they selected a model that allowed for integrated software control of this device from the main application program. They developed a simple program interface to transmit the files to a gateway unit, which then relayed the files to a Novell server. The device had approximately a one-mile range and the added bonus of having a toggle device that could be used to switch to voice mode. Thus, one device could provide the soldier with both voice and data communications.

To let the frontline soldier capture a color still image and transmit it back to a commander, the team had to select a video capture system and integrate and program the appropriate components. The team selected a 16-bit ISA still-imagery video capture card that allowed a National Television System Committee video image to be gen-locked and overlaid over a VGA image (gen-locked is when two video signals are synchronized so they can be overlaid one on top of the other). An important feature of this card was that it provided both VGA and NTSC outputs. This was necessary to drive the helmet display, which required an NTSC input for viewing video imagery. This overlay feature let the video image appear in a window within the overall application program, without taking up the full screen. Most video capture equipment did not allow for such tight integration with other programs.

For the video sensor, the team selected a state-of-the-art cigar-sized daylight color camera, a Sony XC-999, for its resolution, portability, and ability to power the camera from a 12-volt source. (This camera was very advanced for its day and remained the camera of choice for many developers for years to come.) They also designed an external plastic case to house the camera and digital compass. The digital compass selected was from KVH, a digital compass manufacturer, and allowed for custom programming interfaces through a serial port. The team installed two small toggle switches on the case to let the soldier capture an image through a freeze-frame technique. The signals were fed through a wiring harness, which consisted of plastic-coated copper-stranded wire encompassed in cloth mesh tubing. Velcro fastened the video capture enclosure to the soldier's suit.

The soldier captured the actual images by viewing a green-type monochrome live video display in his or her binocular helmet display and pressing a small capture button to freeze the image. The digital compass, which also had an API and serial connection,

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National Training Center-94 Soldier System as well as Task Force XXI were large war game exercises conducted in the mid 1990s, in which frontline soldiers used a ruggedized portable computer in field exercises at Fort Irwin, California, to effect command and control operations.

The Army's main focus, however, was on producing an integrated fighting system. In 1993, it held a kick-off meeting to initiate the development of Land Warrior, a weapon system that, amongst many things, could identify a soldier's location, his or her fellow troops, and the enemy. First and foremost, the system aimed to enhance a soldier's ability to move, shoot, communicate, and survive in modern warfare. To achieve this, the Land Warrior System relied on communications, command and control, computing, intelligence, sensor, and reconnaissance (C4ISR) technologies.

The Army leadership liked the SIPE system's capabilities, so they incorporated many of its functions into Land Warrior. However, they also added new functions and tried to achieve a lighter, smaller, lower-powered, and more rugged system. Like any successful wearable computer or computing system, Land Warrior had to be easy to use, weigh almost nothing, work all day, and be comfortably placed and conveniently located.

tracked the direction the camera was aimed at the time of capture, as well as the soldier's direction of travel for navigation purposes. The signals from both the camera and compass were fed through a cloth mesh tubing wiring harness. LEMO (a manufacturer of various specialty connectors) and military-type circular connectors were used on all external connections for strength and reliability under harsh conditions.

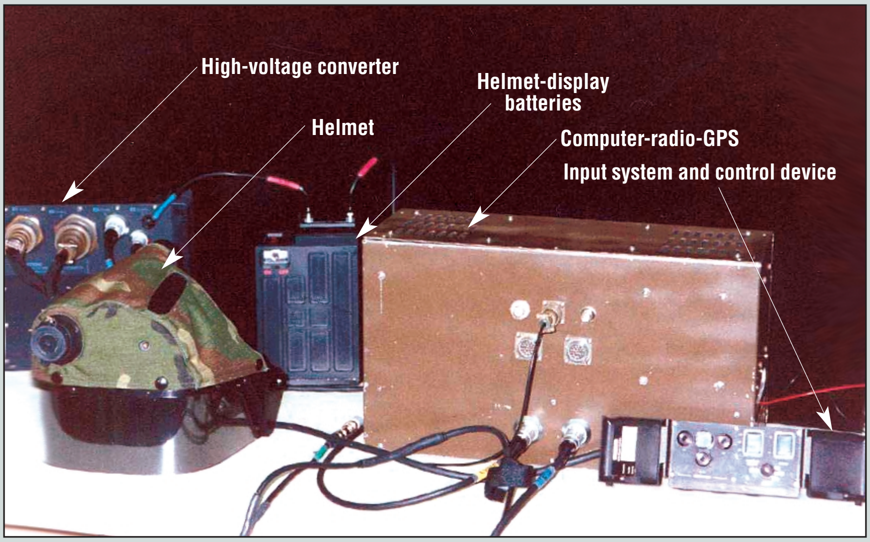


Figure A. The Soldier's Computer.

Interface

To interface the VGA output from the computer and capture system to the monochrome binocular helmet-worn display that S-Tron designed, and to interface to a custom joystick controller, Dick Tuttle's display team from the Electronics Technology and Devices Laboratory of the Army Research Laboratory designed a custom input/output card. The synchronization signal had to be slightly modified to display properly in the helmet. This card also multiplexed the video signals from the weapon-mounted thermal weapon sight and the daylight color camera, directing the signals either to the video capture card or directly to the helmet. The card also provided standard keystroke inputs from the custom joystick to the keyboard and mouse input ports on the single-board computer.

Storage

To store the operating system, application program, captured still images, and maps, the team installed a 3.5-inch form factor 40-Mbyte ruggedized hard disk along the case's inside perimeter. It could withstand 10G operating and 100G nonoperating shock values. It had an initial grounding problem early in the testing that resulted in some hard disk crashes, but once that was rectified with a ground strap, none of the 10 units had a hard disk failure.

Power sources

Two nonrechargeable lithium batteries (BA-5590s) provided three to five hours of operating time. The system's average power consumption was 19.5 Watts for the computer, radio, GPS receiver, and daylight color camera. The helmet-mounted display was powered by its own separate battery and voltage inverter. The system bus was powered by feeding the battery voltage to two separate DC-DC converters with appropriate inline fuses. The entire system was enclosed in a 16″ × 9″ (with a 6-inch depth) aluminum chassis with shielding material added to reduce electromagnetic interference with another voice radio that the soldier used. The system was mounted on a backpack frame and weighed approximately 18 pounds including the two batteries and external camera and compass case. (This did not include the helmet assembly and its power source and inverter. The high-voltage inverter used with the display added significant weight to the system.)

Developing system requirements

In 1994, the Army began a formal requirements process, quantifying battlefield functions and required operations in a performance-based document known as an *Operational Requirements Document*. An ORD defines a desired system's functions, operational capabilities, and performance, quantifying many performance parameters with both threshold and objective values. Before a system can be fielded, it must demonstrate threshold values of key performance parameters listed in an ORD in contractor and development testing and operational testing.

For Land Warrior, the Infantry School at Fort Benning, Georgia, provided the initial fighting doctrine as described in the ORD. The year-long process involved numerous meetings with both users and technical experts, who reviewed, in detail, the requirements' feasibility and applicability. For the next phase—material development—the Training and Doctrine Command System Manager for Soldier Systems at Fort Benning (a government program management office) presented the user requirements to the program manager's office, Program Manager (PM) Soldier at Fort Belvoir, Virginia. (The Infantry School still reviews changes made to these requirements.)

After the Army documented the formal system requirements in the Land Warrior

Software for the Soldier's Computer

The software system employed the legendary Disk Operating System, with a custom package developed in C with a windowing toolkit. This let the system emulate a Windows environment and let the user select software buttons using a joystick interface that emulated a mouse. The main menu navigation bar at the top of the screen let the soldier select the different functions: mapping and navigating, sending and receiving reports, using video mode (for both capture and weapon firing), communicating, and accessing reference material.

For mapping and navigation, soldiers could see both their own location, provided by their GPS receiver, and that of their fellow soldiers indicated as small icons on a scanned and registered map.

The reports section let platoon leaders send and receive several basic battlefield reports. They could construct the reports through a series of pull-down menus, requiring very little typing. They could display a virtual keyboard to construct fragmentary or operational orders when necessary. The video mode let a soldier see a video feed from either the Thermal Weapon Sight or the daylight color camera in his or her monochrome (green on black) helmet display. The soldier could then choose to capture one of these images to send back to the base station. The system automatically time- and date-stamped all images with the sending unit's identity and logged the images into a video database. However, it first compressed the raw images into JPEG files, which could be transmitted in approximately 30 seconds.

The reference material section consisted of several scanned images of enemy fighting vehicles for field identification purposes along with information about the weaponry characteristics. Also included were common field manuals, evacuation procedures, first-aid information, range card procedures, and prisoner of war procedures.

ORD, the program manager developed a performance-based system specification, stating what the system should do but not how it should do it (for example, the specification might say "transmit reports" but not "transmit reports using an FM-based digital radio"). For interoperability reasons, interface standards were specified between components and for external connections to other systems.

The PM Soldier Systems and Project Manager, Soldier Electronics offices, under the Program Executive Office, Soldier, were primarily responsible for developing the Land Warrior system. They had to write the *system performance specification* and contract for developing the system. An SPS translates operational requirements and other system constraints into system requirements and system architecture. The Army awarded the Land Warrior contract to a consortium of contractors, who worked with the government to allocate requirements to the subsystem level. The contractors performed detailed design, build, integration, and test tasks to produce the system.

Key design factors

A significant challenge facing Land Warrior was keeping pace with current technology and implementing a modular replacement strategy to avoid maintaining an obsolete system. The Army aimed to leverage mature and emerging technologies, packaged for the warfighter's environment, to field a supportable weapon system. However, while incorporating the latest trends, the system still had to satisfy its ORD requirements and the constraints of the Army's Joint Technical Architecture.

In addition, the Land Warrior Integrated Process Teams (IPT) of government and contractor design engineers had to make key design decisions on technical standards, approaches, and tools used to build the devices. Such decisions had to facilitate an open, modular, and flexible technical architecture that suited the soldiers and could operate in their environment, including under water, at extreme temperatures, and under constant abuse. At the same time, the system had to minimize audible, radio frequency, infrared, and visible emissions. So, the IPT had to ask design trade-off questions such as, rotating disk or semiconductor (flash) memory? Infrared communications or Bluetooth? AMLCD (Active Matrix Liquid Crystal Display), LOCS (Liquid Crystal On Silicon), or OLED (Organic Light Emitting Diode) display? Wireless, USB, or FireWire? PCMCIA or RS-232 interfaces? Centralized power or numerous batteries? Modular or integrated?

Furthermore, Land Warrior has been incrementally built and tested using the rapid prototyping approach. Both the requirements and specification evolved as the IPT learned lessons throughout the development process. Early testing identified the problems of obtaining adequate bandwidth and range from the communication system, because Land Warrior requires transmitting voice, data, and imagery within a squad.

In Fall 1999, the Land Warrior team of government and contractor engineers started working on the first rugged design of Land Warrior, Version 0.6. They aimed to present it at the Joint Contingency Force Army Warfighting Experiment (JCF AWE) in September 2000 (see Figure 3). This preliminary effort used commercial off-the-shelf and government-furnished components packaged to survive the soldier's environment.

The JCF AWE

Soldiers equipped with the Land Warrior, Version 0.6 participated in three missions during the JCF AWE. The system provided a tremendous advantage to a platoon of infantrymen from the 82nd Airborne Division (Fort Bragg, N.C.) in this field test against the conventionally equipped opposing force at the Joint Readiness Training Center in Fort Polk, Louisiana.

Figure 3. Land Warrior Version 0.6, September 2000.

The first mission was to parachute onto and secure an airfield at night. After reattaching their HMDs and headsets and turning on the system, the soldiers could see their own location, where they were headed, and the location of their fellow troops overlaid on the assembly area map. Wireless voice and message communication, previously not available to all soldiers, proved beneficial, and everyone reached the assembly area in record time.

The second mission, which began at 2:30 am, was an assault on a village with several buildings (to simulate urban terrain) and enemy soldiers. The Land Warrior system automatically transmitted position reports for eight leaders in the platoon to higher-echelon software systems.

The third mission was a night ambush. Land Warrior let the soldier's view their night vision image intensifier with one eye and their HMD with the other. (A rubber boot attached to the HMD eliminated detection by reducing light emissions.)

PM Soldier learned numerous lessons from these exercises. For example, the system's disposable $LiMnO_2$ batteries and lower-energy Li-ion rechargeable batteries were too expensive and impractical, so the system needed different power sources. Other lessons learned included the need for fewer cables with less exposure, improved reliability and ruggedness, and a reduction in electromagnetic interference. Overall, however, the system performed well, improved fighting capabilities, and impressed the soldiers.

Land Warrior, Version 1.0

After completing the JCF AWE, PM Soldier and the consortium of Land Warrior contractors began to design the first field version (Version 1.0), now called the Land Warrior Initial Capability (see Figure 4).

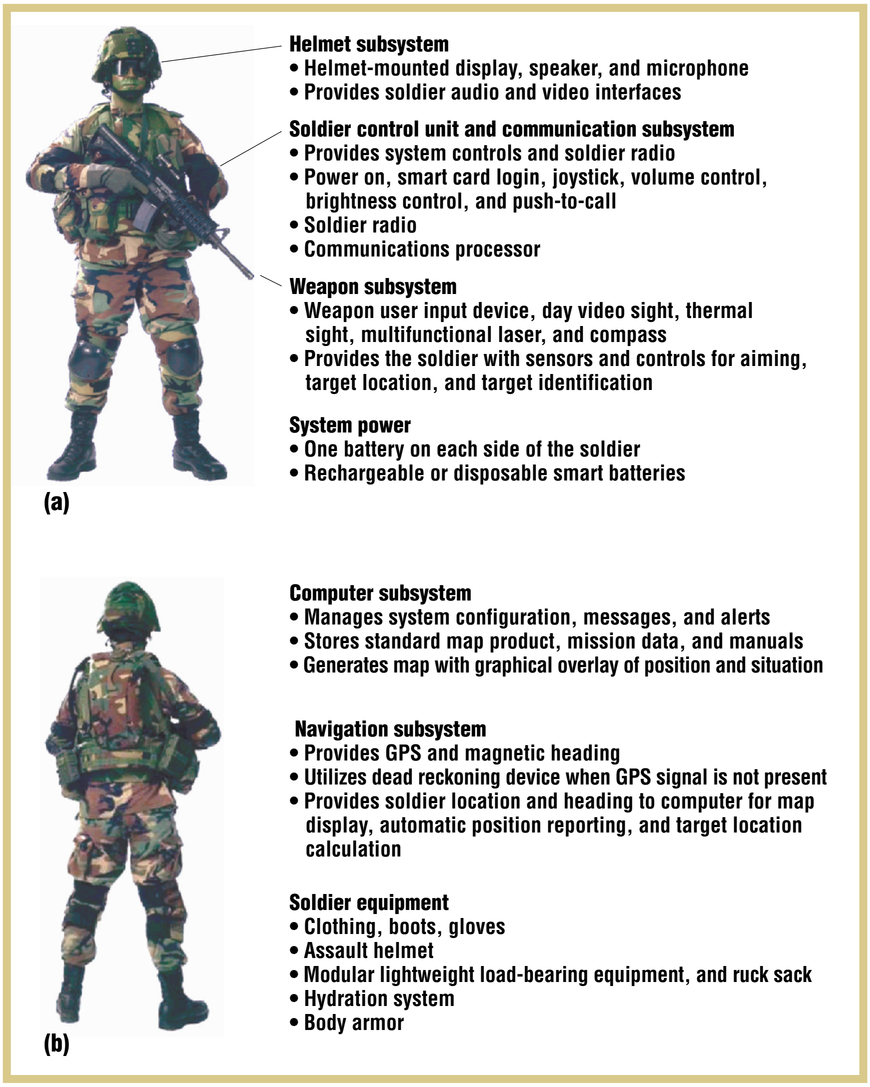


Figure 4. Land Warrior Initial Capability, Version 1.0: (a) front and (b) back.

Figure 5. Land Warrior's computer subsystem.

Design rationale

The IPTs incorporated the lessons learned and addressed other fighting and operational issues, leveraging commercial components, packaged and configured in a custom fashion to meet battlefield conditions and requirements.

To address the battery problems, the IPT decided to use smart batteries that included an SMBus 1.1 (System Management Bus, Version 1.1, a commercial standard) readout of the battery's charge status and other data. However, SMBus had to be converted to USB, so a smart-battery adapter was developed. In addition, the IPT used novel power management techniques to extend battery life. Now, when the soldier flips up his or her HMD, a switch turns off all video components and places the computer in standby mode (voice communications and other functions still operate in this mode).

The integrated handheld display and keyboard let platoon leaders view maps with a larger display (in addition to the HMD) and rapidly enter graphics and text for mission planning. However, manufacturers are still trying to develop a color SVGA display (800 × 600), six to nine inches diagonal, which is the ideal size from a human-factors and form-factor standpoint. This display would allow for easy map reading while still fitting in a soldier's Battlefield-Dress-Uniform cargo pocket. Furthermore, display manufacturers are working to make a touchscreen display that is visible in all lighting conditions and meets all other environmental requirements, such as a wide range of operating temperatures.

Incorporating lessons learned from Land Warrior Version 0.6, which used a centralized server, Land Warrior Version 1.0 uses a more distributed software architecture. Also, the Land Warrior system does not contain enough storage for worldwide coverage of maps, and wireless downloading of maps is problematic owing to bandwidth issues. PM Soldier thus developed a separate system, called the Mission Data Support Equipment, to help load mission data before a mission. The MDSE consists of a laptop computer and USB-to-Ethernet adapters. Its software includes the Mission Data package, which lets soldiers organize unit tasks and create situation maps, help files, operation orders, and mission overlays.

Major subsystems and components

The Land Warrior system is characterized by multiple integrated subsystems to achieve a more effective infantry unit. The computer subsystem (a Pentium) runs Windows and is the core of the Land Warrior computer subsystem (see Figure 5). It weighs 1.79 pounds and consists of the computer assembly, flash memory, and video board, packaged in the computer subsystem box. The box has a single external connector for power, USB, and IEEE 1394 FireWire connections. The flash drive stores Land Warrior application software, National Imagery and Mapping Agency (NIMA)-approved map products, field manuals, and system information.

Figure 6. Helmet display.

Figure 7. Soldier control and communications subsystem.

The helmet subsystem (see Figure 6) consists of the HMD, hearing devices, and microphone devices. The HMD is an 800-×-600-pixel full-color display using an organic light-emitting diode display viewed through a high-efficiency plastic prism encased in a protective housing. It allows the soldier to interface with all Land Warrior functions. During tactical movement and contact, the soldier will primarily use it to view his or her location, other friendly locations, and his or her direction of travel (heading) superimposed on the map.

The soldier control and communications subsystem (see Figure 7) is the system's primary soldier input and interface device. The soldier control unit lets soldiers manipulate system configurations and generate and send tactical messages. The communications subsystem transmits voice and data so that soldiers can communicate in their squad. A mesh concept that forwards packets to soldiers in multiple hops enhances the system's range, and the Army will issue an AN/PRC-148 multiband inter/intra team radio to squad leaders (and above) for longer-range communication and interoperability with higher-echelon radios.

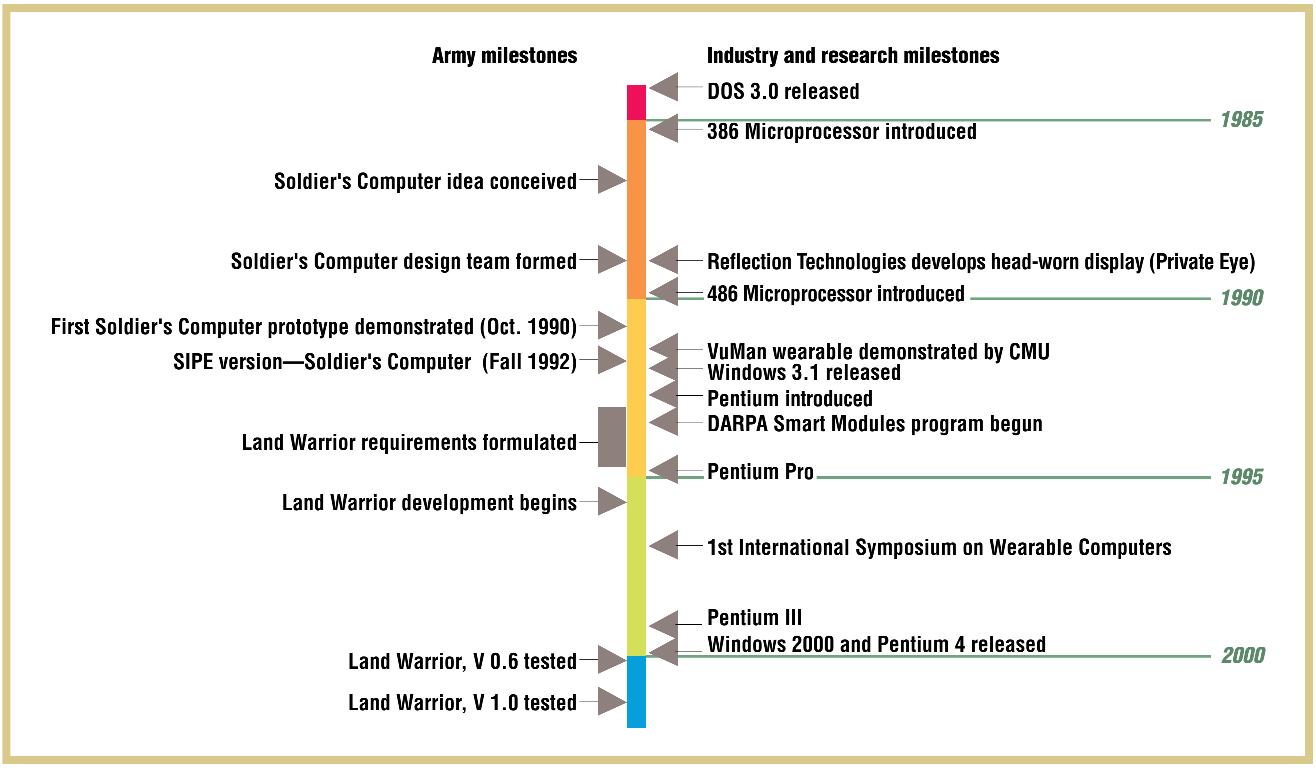


Figure 8. A timeline of Army wearable computer systems versus industry and academic developments.

The weapons subsystem (WSS) has a mounted Daylight Video Sight and TWS for sighting. Depending on the duty position, the soldier can mount currently issued aiming lights, an infrared pointer, or a multifunctional laser. The laser combines multiple functions of currently fielded systems into one device and integrates a laser range finder and digital compass. A peg grip on the weapon's stock has buttons that let soldiers make calls, transition between sighting systems, capture images, and locate targets without removing a hand from the weapon. The WSS routes all target information and image capture to the computer, which automatically determines target location and fills message fields as applicable.

The navigation system integrates a GPS receiver with an antenna on the left shoulder, a magnetic compass heading sensor, and a dead reckoning module, which extrapolates the last known position should the GPS fail or receive insufficient signal. It also graphically overlays the soldier's position on a digital map, along with positions of other Land Warrior systems, which are automatically broadcast periodically.

The full Land Warrior system includes not only the electronics but also all the other items that constitute the soldier's combat load, including clothing, armor, weapons, and ammunition. Many integrated elements comprise the Land Warrior fighting system, not just a computer—though it is a key component. For more information, see https://www.pmsoldiersystems.Army.mil/public/default.asp.

Land Warrior continues to evolve from a system built around the soldier's equipment, to a system integrated with the soldier's equipment, toward a system built within the soldier's equipment (see Figure 8). It will progress iteratively from an all-in-one wearable system that replaces portable C4ISR products and enables soldiers to fight, to a ubiquitous system that embeds those products into an all-for-one system that a soldier wears to fight. The Objective Force Warrior system focuses on electronics embedded in an integrated combat uniform, and researchers at Carnegie Mellon University and Georgia Tech are exploring similar concepts.[4,5]

In addition, the Army continues to investigate advances in wearable computing devices and the use of handheld devices to augment or replace wearable systems in certain situations. Under various research initiatives within CECOM's Command and Control Directorate, the Army is exploring advances in computer hardware and software applications that can run on small portable-computing platforms. Also, Land Warrior, Version 1 (now called Land Warrior IC) has demonstrated an early version of speech recognition, one of its objective requirements. There are also two small business innovation research (SBIR) contracts for "heads-up situation awareness for the dismounted warrior." These contracts address the need to superimpose situational information on the HMD to help avoid fratricide. Suomela and Lehikoinen presented similar concepts for augmented reality at ISWC 2000.[6] Government research engineers are examining low-power computing devices, tablet PCs, and handheld computing devices. As handheld devices become more powerful, the need for a wearable computer for certain applications diminishes. Along these lines, there is also an SBIR solicitation (request for business contract proposals) calling for a location-aware handheld computing device with integrated long-range (greater than 500 km) communications. However, wearable computers will always have a place on dismounted soldiers, who need both of their hands free to perform missions while the computer augments their capabilities.

In the applications area for mobile military computing platforms, four technologies show particular promise:

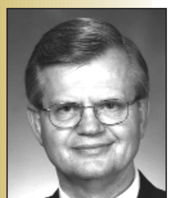
- Intelligent agents on wireless wearable computers communicating with remote servers
- Java-based collaboration tools with whiteboarded military maps to plan and rehearse missions
- Speech recognition in the battlefield's high-noise and high-stress environments
- Mobile wireless database retrieval and synchronization with handheld devices

Java and the Jini architecture show promise for many portable networked applications that support the network-centric battlefield. The Army is exploring Bluetooth and other communications technologies to reduce cabling issues associated with wearable computing devices.

All these technologies will play a key role in the Army's vision of the future, as its Objective Force Warrior system emerges over the next 10 years. Soon, the Army will have soldiers with integrated battlefield systems consisting of the Land Warrior system. For now, the granddaddy of it all, the backpack-sized Soldier's Computer, will soon become part of the Smithsonian's permanent collection, so you'll be able to see it on a future visit to the Washington D.C. area.

the AUTHORS

Matthew J. Zieniewicz is a senior electronics engineer for the Research, Development, and Engineering Center, US Army CECOM. He formed and led the initial Soldier Computer team for the Soldier Integrated Protective Ensemble and was the initial computer-radio-GPS technical lead for the Land Warrior system. He is exploring mobile database issues, Web technologies, and handheld applications for the dismounted warfighter and advanced system architecture issues for the Objective Force Warrior. He received a BSEE and an MSEE from Fairleigh Dickinson University, and he did post-graduate work at Princeton University. He is a licensed professional engineer in the state of New Jersey. He is a member of Eta Kappa Nu, the national electrical engineering honor society, and of the ACM, IEEE, and Internet Society. Contact him at matthew.zieniewicz@us.army.mil.



Douglas C. Johnson is a system engineer on the Land Warrior program at Fort Monmouth for PM Soldier Systems, specializing in computers, personal area networks, and interoperability with other Army Battle Command Systems. He received his BS in electrical engineering from Rensselaer Polytechnic Institute, N.Y., a masters in electrical engineering from NYU, and a masters in computer science from FDU. He is a member of the IEEE and Army Aviation Association of America. Contact him at douglas.johnson@us.army.mil.

Douglas C. Wong is team leader for CECOM RDEC's Command and Control Directorate. He manages the electronics technologies, products and systems integral to the Land Warrior System. He also leads a team of technical subject matter experts, and technical, readiness, software, and acquisition managers, who come from the depth and breadth of CECOM organizations. He has a BS in aerospace engineering from Polytechnic Institute of New York, an MBA in strategic management of technology from Monmouth University, N.J., and he is a graduate of the Army Management Staff College, Fort Belvoir, Va. He is a member of the Army Acquisition Corps. Contact him at douglas.wong@us.army.mil.

John D. Flatt is a senior electronics engineer for the US Army's Program Manager, IE. He worked on the initial Soldier's Computer effort under SIPE and has over eight years experience with mobile computing. He received a BSEE and MSEE from Fairleigh Dickinson University. Contact him at john.flatt@us.army.mil.

REFERENCES

1. M. Nugent, "The Soldier Integrated Protective Ensemble," *Army Research, Development, & Acquisition Bulletin*, Sept./Oct. 1990, pp. 1–5.

2. S. Mann, "An Historical Account of the 'WearComp' and 'WearCam' Inventions Developed for Applications in 'Personal Imaging,'" *IEEE Proc. 1st Int'l Symp. Wearable Computers*, IEEE Press, Piscataway, N.J., 1997, pp. 66–73.

3. A. Samilagic et al., "Very Rapid Prototyping of Wearable Computers: A Case Study of Custom versus Off-the-Shelf Design Methodologies," *Proc. 34th Ann. Design Automation Conf.* (DAC 2002), ACM Press, New York, 1997, pp. 315–320.

4. D. Marculesa, R. Marculescu, and P. Khosla, "Challenges and Opportunities in Electronic Textiles Modeling and Optimization," *Proc. 39th Design Automation Conf. 2002* (DAC 2002), AMC Press, New York, 2002, pp. 175–180.

5. S. Park, K. Mackenzie, and S. Jayaraman, "The Wearable Motherboard: A Framework for Personalized Mobile Information Processing," *Proc. 39th Conf. Design Automation* (DAC 2002), ACM Press, New York, 2002, pp. 170–174.

6. R. Suomela and J. Lehikoinen, "Context Compass," *Proc. 4th Int'l Symp. Wearable Computers*, IEEE CS Press, Los Alamitos, Calif., 2000, pp. 147–155.

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