

Using a wearable computer for continuous learning and support

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A wearable computer with an electronic performance support system can provide continuous learning and support to mobile workers. This system allows mobile users to ask for advice, receive instruction, access productivity tools, communicate with others, and assess their knowledge on a continuous basis. Workers can get this support when they need it, where they need it. Compared to traditional training and support, this new technique may provide substantial performance improvements. We are developing an architecture for this type of support system and are currently investigating the use of this system to help mobile factory workers perform their tasks.

1. Introduction

The performance of factory workers is heading for a crisis. Downsizing strategies result in fewer workers doing more work with less help. Also, many factory workers are being asked to use or maintain increasingly sophisticated manufacturing systems while receiving less and less training and/or support to keep these systems running. The effect of these trends is to reduce worker specialization and to produce a growing need for workers who can adapt quickly to a variety of situations that use a wide range of skills [15].

The traditional approach to solving this problem is to provide additional training for the workers. Modern training techniques often use interactive, computer-based technologies to create self-paced learning modules that are easy to copy and distribute. However, this technique often fails to produce the desired results. Worker performance may not actually improve. One possible reason for this failure is that instructional developers appear to be applying new technologies to old approaches of training. As a result, some advances in educational technology have had little real impact on the workplace [3].

It is now possible to use a completely new approach to solve these worker performance problems. Traditional training focuses on the training event, ignoring the needs of the workers afterwards. This approach is event-centered. It does not include the environment in which the work performance occurs and often fails to provide the desired performance improvements [5].

To maximize the benefit of advanced educational technologies on the factory floor, a new approach is needed. This new approach must include all elements of the learning process, such as instruction, practice, reference materials, and follow-up support. This approach is more similar to learning on the job. Table 1 compares assumptions made by the traditional training approach to those made by an on-the-job training approach.

On-the-job training is effective, but it is very expensive to provide and the instruction is rarely consistent. Also, it is very challenging to provide training and support to workers

Table 1

Comparison of traditional versus on-the-job training assumptions.

Traditional training approach
The information that a worker needs to know to do a job is mostly static.
Certain facts, concepts, and procedures must be learned before a worker begins to perform a task.
Training takes place away from the job task, in a classroom.
Learning occurs during a specific time period (e.g., the training class).
Learners remember what they learn in a class, then apply the knowledge later.
Practice of the actual job task does not occur during training.
Self-directed learning is inefficient and often useless in the workplace.
After training, the worker is an expert at performing the job task.
There is no evaluation of the effect of training on actual task performance.
On-the-job training approach
The information that a worker needs to know to do a job is very dynamic.
A worker can perform the task poorly at first, but gets better over time.
Training takes place at the job site, while performing the job task.
Learning occurs continually over time.
Learners remember what they learn on the job and apply the knowledge immediately.
Practice occurs immediately while performing the job task.
When given specific goals and rewards for work performance, workers can perform self-directed learning.
To become better at the task, the learner continually needs time and guidance from experienced, expensive experts.
There is immediate, obvious evaluation of the effect of training on actual job task performance.

who must move throughout a plant to perform their jobs. Examples of mobile workers include quality assurance inspectors and maintenance workers.

2. A new approach: Electronic performance support system

Due to recent advances in information technology and educational technology, it is now possible to develop sys-

Table 2
Comparison of traditional training versus FAST.

Traditional training
Event-centered, not integrated with everyday work environment
Training provided before worker needs it
Trainer responsible for teaching, worker responsible for learning presented material
Assessment based on student satisfaction and attainment of classroom objectives
Factory automation support technology
Worker-centered, integrated with everyday work environment
Support provided when worker needs it
Worker responsible for using support resources to accomplish job task
Assessment based on worker's job performance

tems that help workers as they perform their tasks. Gloria Gery coined the term "Electronic Performance Support System" [4], to describe a system that provides task-specific information, training, and assistance when it is most needed – when the worker is trying to perform the task. Electronic performance support systems may include advanced information and educational technologies such as hypermedia, expert systems, computer assisted instruction, and intelligent agents [2]. Our research extends the electronic performance support system concept by hosting the electronic performance support system on a wearable computer. This system can provide support to mobile workers when they need it, where they need it, anywhere on the plant floor.

Providing performance support by using an electronic performance support system on a wearable computer is very different from the traditional training approach. This new approach shifts the focus of learning from training/teaching to supporting/enabling workers while they perform their tasks. When a worker has trouble performing a task, the worker can ask for advice, receive instruction, access productivity tools, and assess his/her knowledge from anywhere in the plant. We call this new system "Factory Automation Support Technology (FAST)" [12,13]. Table 2 summarizes the differences between a traditional training approach and the FAST approach.

To develop learning systems that support performance on the job, we must examine how workers typically learn on the job. As discussed earlier, on-the-job learning is very different from typical classroom-based learning. On-the-job learning is much more informal and individualized. It is scheduled as the need arises and learning occurs while doing the job, rather than as the result of some discrete instructional event.

Table 3 describes strategies that may be used by workers who are performing on-the-job learning. The strategies include requests for information or support made by on-the-job workers and the responses that need to be provided by the on-the-job trainer. An electronic performance support system must provide the ability for an on-the-job worker to ask these questions and get the appropriate responses.

Table 3
Typical on-the-job learning strategies.

Worker requests
Why should I do this?
What is this?
What is this related to?
How do I do this?
Why did this happen?
Give me an example.
Teach me how to do this.
Help me do this.
Watch me while I try.
How am I doing?
Do I understand?
How does this work?
Is this like . . .
What do you think would happen if I did this?
Where is the information I need?
How did I do this before?
Type of support response from on-the-job trainer or support system
Explanations, examples with consequences
Definitions, illustrations, descriptions
Cross reference, similar activity description
Demonstration, checklist, procedure description, flowchart
Explanation of events, log of activity
Demonstration
Interactive training/tutoring, practice activities, assessment
Interactive advisor, job aids
Monitoring systems, feedback on success
Assessment, encouragement
Descriptions of what you have done, summary of assessment
Explanations, diagrams, demonstrations
Comparative explanations, similar examples, case histories
Predict outcomes, simulation
Boolean search, index
Logbook, notes

Novice workers tend to quickly move from one type of request to another, often repeating requests until the worker develops a sense of how best to attack the problem [6]. These workers try to develop an understanding of exactly what must be done, and then move toward an understanding of how to do it. This is a highly-individual process that proceeds in no particular sequence. The actual steps followed may also vary from problem to problem. As workers develop an understanding of the task procedures, workers seek a more in-depth understanding of the concepts, rules, and principles that relate to the job tasks. Workers may return to these strategies even after mastering a task. This occurs, for example, when an unfamiliar problem occurs with one of the mastered job tasks.

So, performance support allows a worker to get task support when the worker needs it, in a way in which the worker

is most comfortable. A wearable computer can provide this support right in the worker's job environment. Performance support differs from other support approaches, such as electronic reference, interactive training, help, or expert systems, because performance support integrates a variety of learning strategies into a single application. The worker selects the most appropriate support strategy for the current task and the worker's learning style. This highly flexible, individualized process sets performance support apart from other learning approaches.

3. Factory automation support technology (FAST)

The main component of the FAST system is a database of information (or "infobase") containing the materials a worker needs to support the performance of a particular task. The information may be textual, such as on-line operating procedures, product information, specifications, reference manuals, up-to-the-minute change orders, glossaries, policies, messages from a supervisor, and a list of where to go for additional help. The information may also be visual or auditory, such as circuit diagrams, reference pictures for inspection tasks, and audio/video demonstrations of procedures. Each of the elements can be indexed according to function, location in the plant, purpose, intended audience, security restriction, and level. Driven by an individual worker's needs, the system can provide tailored access to the information. For example, novices may get detailed instructions at every step of a procedure. Experts may get a high level outline view which also enables them to quickly link to any single step in the procedure.

The infobase is connected to applications which directly help the worker to perform tasks. The infobase includes tools which help the worker to use the appropriate knowledge, procedures, or rules to perform a specific task or to solve a specific problem. The tools may consist of advisory or expert systems for problem structuring, diagnosis, or decision-making. On-line advisors may help a technician to diagnose a problem by automatically suggesting items to check. Using the model of an intelligent tutor, the system can provide active intervention in the form of advisory warnings, suggestions, or questioning. For example, in a factory repair situation, the support system can provide all of the following: instrumentation to monitor a problem, tools to analyze the data collected, advice on narrowing-down the problem and instruction on the required repair procedure [7]. This instruction can be followed by an opportunity for the worker to use the system to examine similar kinds of problems or to simulate other faults and subsequent diagnoses.

To encourage the worker to perform self-directed learning for specific tasks, the system can include detailed interactive training. This training may be initiated by the worker, structured according to some kind of certification process, or automatically initiated by the system when the system recognizes an error or difficulty.

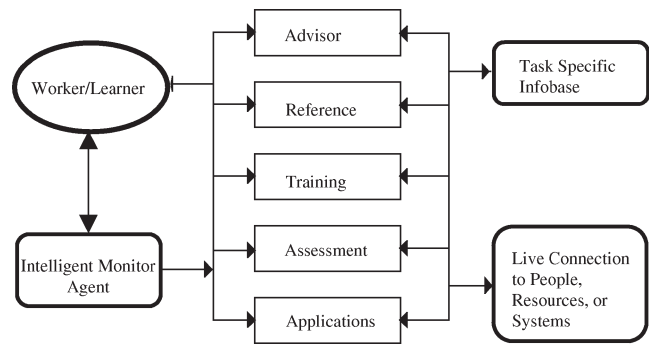


Figure 1. FAST architecture.

To help the worker to identify knowledge deficiencies, the system can include assessment support. The purpose of assessment support is to identify when the worker may need to acquire new knowledge or skills, then to guide the worker through the process of getting them. The assessment data can be used by the worker, retained by the system for controlling access to certain kinds of information or equipment, or used to certify expertise in a specific domain.

3.1. FAST architecture

Figure 1 shows the architecture of the worker-accessible portion of the FAST system. The worker/learner is free to access any of the components directly. As described earlier, the components of the task-specific infobase include an advisor, reference information, knowledge and skill training, a performance assessor, and various support applications. The system can also use a local network, the Internet, electronic mail, and videoconferencing to connect to other systems, resources, and people. Using a wireless network, the worker can rely completely on remote computing and storage resources. This technique allows the mobile worker to carry only the necessary input/output devices, such as a pointing device and a display.

The primary purpose of the intelligent monitor agent is to anticipate worker problems and to automatically link to the component of the system that is most likely to help the worker. The intelligent monitor agent consists of background applications that continually monitor several worker parameters. These parameters may include actions within the FAST software, external activities required by the worker to perform the current task, environmental sensors, or even biological indicators of the worker's emotional and physical states. The values of some of these parameters can result in immediate changes to the user interface, such as the presentation of relevant, helpful information.

The system also logs the values of other parameters. These values are analyzed and integrated with other workers' data at a central learning aggregator site. Over time, the learning aggregator becomes a repository of shared experience and knowledge for all workers. When the workers are not using the system, the learning aggregator can access mainframe-scale computing resources to analyze all the worker data. This major analysis allows the system to

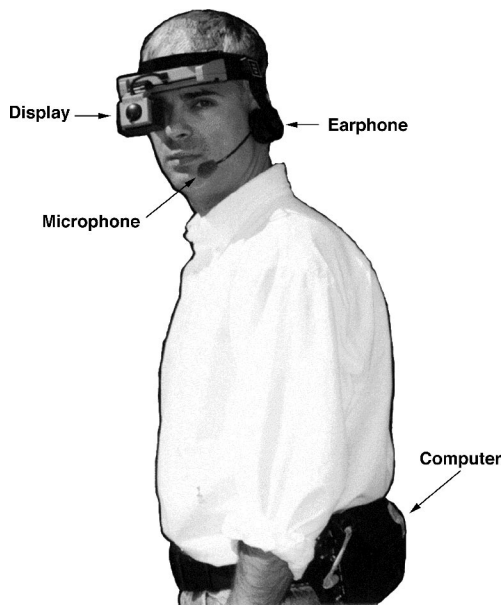


Figure 2. Wearable computer system.

extract new procedures, suggestions, and rules that can be added to the infobase. This new information can be checked for accuracy and value by an experienced worker or supervisor. Then, these new support aids can be downloaded to individual wearable computer units at the beginning of each work day. In this way, each worker automatically benefits from the combined experience of all the workers.

3.2. FAST wearable computer

To test the FAST concept, we combined a customized, wearable computer with a multimedia electronic performance support system. The wearable computer allows the user to retrieve information, enter data, ask a question, or collaborate with another person wherever the user goes. Our software-based electronic performance support system integrates multimedia information, tools, databases and methodologies to help users perform specific tasks in a factory setting.

The current FAST hardware consists of a wearable, voice-activated, general purpose computer system that is equivalent to a typical desktop computer. Figure 2 shows the major hardware components. The components are:

- A head-mounted display (Kopin headset 640×480 monochrome) that allows the worker to continue working while looking at text, drawings, or videos that help the worker to perform specific job tasks.
- A unidirectional, noise-cancelling microphone (part of Kopin headset) that lets the worker enter and request information while keeping the worker's hands free to work on a task.
- An earphone (part of Kopin headset) that allows the worker to receive auditory information.

- A wearable computer (Computing Devices International Flexible Wearable PC) with 486–75 MHz CPU and 20 MB of RAM that runs local applications.
- In the computer, a wireless communications link (Digital RoamAbout PCMCIA 900 Mhz network adapter) to send or receive up-to-date information from remote servers anywhere in the world.
- In the computer, a customized, rechargeable, nickel metal hydride battery pack with about five hours of battery life to supply power for the components.

The functionality of the FAST system can be extended to include optional input devices (e.g., low-cost, digital camera such as QuickCam for remote collaboration), user sensors (e.g., heart rate monitor [14]), and environmental sensors (e.g., thermometer). These optional input devices may help users to work together [17]. The devices may also be used to monitor the health and safety of users working in extreme environments such as combat [19], space [1,8], sites of hazardous waste spills [18], and field maintenance of military vehicles [16].

The user of a wearable computer system can interact with the system in a number of ways, including:

- Request information from a local storage device.
- Download current information from a remote file server via the wireless network.
- Collect and store local data for later transfer to a central computer system.
- Request diagnostic assistance from expert systems or case-based help resources.
- Transmit live data from a work site to a central facility via the wireless network.
- Interact with a remote user via audio, video, and/or application sharing.
- Access worldwide information sources through an Internet gateway.

3.3. Industrial applications

We are applying the wearable computer and electronic performance support system to improve employee performance in an industrial setting [11–13,18]. One application helps mobile quality assurance workers to collect real-time quality assurance data from anywhere in a food processing plant. Our system allows a worker to manipulate product samples with her hands while using her voice to enter the desired data. As the quality assurance worker makes entries, the values appear on the head-mounted display and are repeated over the earphone. Figure 3 shows a sample screen from an application used to record the temperatures of meat samples. The screen shows that when a value is out of the normal range, the computer automatically adds a notation and will eventually use electronic mail to notify appropriate supervisory personnel. As the worker enters

Time	Temp	Comments
3:50 PM	41	Temp higher than 40
/	/	/
/	/	/
/	/	/

Buttons: Tenderloins, Dark Meat, Summary, Forms Menu, Erase, Quit

Figure 3. Quality assurance inspection application screen.

the information, the computer transmits it over a wireless network to a central storage computer.

We recently completed a successful field test of our first version of this application. A quality assurance worker first took about 10 minutes training the system to recognize his voice commands. Then the worker spent 30 minutes collecting actual meat sample temperatures on the plant floor. The values were sent over a wireless network from the worker's computer to a database in another computer representing the plant manager's computer. Once in the database, the information could be queried and graphed. Although the plant was so loud that workers needed hearing protection, the quality assurance worker experienced 100% speech recognition accuracy. The worker enjoyed using the system. Since the system relieves quality assurance workers from carrying clipboards, pens, papers, and paper towels to wipe their hands, the worker expected that user acceptance of the system would be very high. In the future, the system will provide detailed procedural support as well as statistical process control feedback.

3.4. Lessons learned

Our work has taught us several valuable, practical lessons about using a wearable computer as a platform for an electronic performance support system in an industrial environment.

- To maximize worker comfort, use light, small, and highly-adjustable wearable computer components.
- To avoid interfering with the worker's tasks, mount the computer components on the back and sides of the worker's waist (unless the worker needs to lie on his back to perform tasks).
- To maximize voice recognition accuracy, use phrases that sound very different from each other [10].
- To minimize the number of voice inputs, let the computer automatically perform many worker tasks (e.g.,

move the cursor to the next entry field, make a notation and notify a supervisor when a value is out of the normal range).

- To improve the usability of the voice input technique, develop applications that minimize navigation and use a very simple, command-based user interface.
- To accommodate worker preferences, develop the training information using a variety of media (e.g., drawings, video), then let the worker select the preferred presentation medium [9].

4. Conclusion

We developed a new approach that provides continuous learning and support to mobile workers while they work. The wearable computer and electronic performance support system provide workers with the information they need, when they need it, where they need it, from anywhere on the factory floor. This approach supports the idea that learning is a highly individualized process that occurs over the entire life of a worker. We also developed and successfully field-tested a version of this system called FAST that assists workers on an actual factory floor.

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