A CyberEdge Journal Reprint

CyberEdge® JOURNAL

The World's Leading Newsletter of Virtual Reality

From Issue #24, Vol. 4, No. 6 Nov/Dec 1994

Application: Motorola Trains Manufacturing Workers

Immersive VR Tests Best

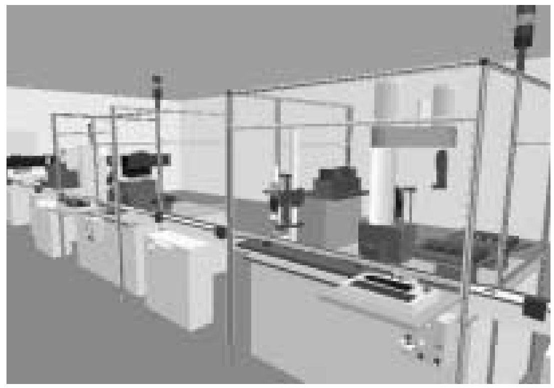
by Ben Delaney

Adams Consulting got what many in the VR community would consider a plum job; building a system to train line workers at Motorola University, in Schaumberg, Illinois. But President Nina Adams, and Consultant Olaf Westgaard, saw this as more than a video game with an industrial look. Thanks to Adams' experience in CBT (computer-based training), and Westgaard's systems design know-how, they put together a system that is not just sexy and high-tech, but has measurable superiority when compared to conventional methods of teaching the same tasks.

The project started in July, 1994, when Art Paton, Instructional Design Manager at the Technology Education Center of Motorola University, and Adams found a win-win situation. Adams would develop a system to train Motorola workers to run the Pager Assembly Line. Motorola would underwrite the development costs, but with the requirement that the system design include methodology for evaluating the relative value of this training method. Adams got a paying job, and material for her masters thesis. Motorola learned a lot about the efficacy of VR training, at a relatively low cost. There is one more winner. The world now has the first test of VR training that included a control group, essential for scientific validity.

Motorola U

Motorola University, the company's corporate training unit, is not just for in-house training. They teach everything from word processing to manufacturing engineering. Every Motorola employee is required to take



Motorola University's Virtual Assembly Line replicates the major functionality of a real pager assembly line.
© 1994 Motorola.

an annual course of their choice, and people from outside the company are also welcome to take classes. But, Motorola U is a profit center, which means that Paton had to see general, long-term benefits in VR-based training.

Motorola needs in-house training for the thousands of workers who are new hires, or require instruction on new equipment. With thousands of workers in plants all around the world, this continual training represents a major expense. Finding ways to do it quickly and cost-effectively are essential.

Frequent training is also required because Motorola has adopted a "run of one" manufacturing philosophy. That means that they want to have a manufacturing process so flexible that they can build just one of any particular product, should their client request it. To do that, Motorola has developed highly flexible robotic assembly lines that demand regular worker training.

One of those lines is the Pager Robotic Assembly Facility, located in Boynton Beach, Florida. Motorola has created a detailed,

On The Edge

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To assist in the development of commercial products incorporating these new concepts and technologies.

CyberEdge JOURNAL
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Immersive Best

Continued from page 1.

working replica of this line in Schaumberg for worker training. Adams and Paton decided to model it virtually for the test case of VR training.

Traditionally, workers who are about to move to the Boynton Beach Pager Line come to Schaumberg for their training. The lab in Schaumberg was built to allow the training to take place without the huge expense of shutting down a live production line. The lab includes five workstations: three where robots assemble pagers, one for quality assurance (QA), and one for laser marking, where logos and other markings are inscribed on the cases. The lab really builds products, not pagers, but souvenir clocks that look just like pagers.

Adams and Paton went into the project with an open mind. The question was whether VR would be as good as the traditional training techniques. Paton told us he “expected a performance hit on the VR-training groups”. However, no one really knew what to expect, so the job was to provide results that Motorola, a high-tech company used to measuring all aspects of its business, could accept as definitive and accurate.

Adams and Westgaard modeled the line using Superscape software for both modeling and world-building. They took hundreds of photos of the facility and equipment, some of which were used for reference, and some for mapping detail onto the 3D models. They modeled all five workstations in the lab, resulting in a model of moderate complexity, about 3,000 polygons.

Training regimen

Manufacturing 451: Introduction to Advanced Manufacturing Techniques, is a three-day program broken into three sections: classroom instruction, laboratory practice, and evaluation. The size of the typical class, 15-25 students, is fine for the classroom component of the training. However, when the students move into the lab for hands-on practice problems can arise. For example, each student is required to demonstrate proficiency in operating the equipment. During the practice sessions, some students, who are intimidated by the powerful robots, hold back, while others are so eager that they grab the lion’s share of hands-on time. In testing, those students who got less time with the machines often perform below average. Adams realized that the VR system could provide an individual “virtual lab” for each student, enabling them to have full and solitary access to all of the equipment, free of embarrassment or penalty for shyness.

The other advantage of a virtual lab is that Motorola can send it anywhere. That could greatly reduce the cost of bringing students from around the world to Schaumberg. Of course, the virtual lab is easily re-programmed when new equipment is brought on line.

To more easily assess the value of the VR training, Adams modeled “a small, measurable unit”. They chose *Setup and Start-up, Running, and Safe Shut-down*. Motorola considers all of this one task – and there are four others involved with manufacturing pagers. *Setup and Start-up* involves a fairly complex sequence of operations – pushing buttons, flipping switches, typing commands at on-site keyboards, and making choices from computer menus – to properly configure the line for whatever product is to be manufactured. *Running* the line is simple, unless something goes wrong, when quickly and safely *Shutting-down* the line is essential.

Challenges

The first challenge that Adams faced was the design of the virtual lab itself. Motorola insisted on a very high level of precision and accuracy. The models were developed from measuring the actual lab space, robots and tooling, as well as with reference to photos and sketches. Key to the project was unlimited access to the lab – being on site in Schaumberg turned out to be critical. Modeling took five weeks, and describing the interactivity in the system took seven more. However, Paton estimates that the cost of developing the VR version of the line provided a saving of close to 99% when compared to the cost of building a real lab

Westgaard told us that Motorola wanted 100% fidelity, and got 100% of what was instructionally important. However, Westgaard is the first to admit that 100% fidelity was not achieved. He explained, “past a certain point, realism detracts from the experience. In VR we focus only on the important things.” The look and feel of the line was instantly recognizable to the trainees, including one who had never seen the lab, but commented, “why that’s the Boynton Beach line!” the first time he saw the VR model. Conversely, trainees who had never been to Boynton Beach immediately recognized the equipment when they arrived there for the first time.

Feedback is a crucial function in any training scenario, and it turned out that sound was a critical factor in the Pager Line model. To provide the realistic sound needed,

Immersive Best

Continued from previous page.

Adams spent many hours lurking around the equipment, recording the sounds of the line in high fidelity. These recordings were converted to .WAV files, and attached to the equipment and activities in the world. They were important because, as Adams explained, in many cases the sounds, such as the conveyer belt starting, are the only feedback to the line operator.

One of the greatest challenges was modeling error situations, or modeling scenarios that would let the machines react realistically when things went wrong. Since there are a nearly infinite number of errors possible, it was decided to create models that would react as the real machines do, regardless of input, rather than to try to foresee every possibility.

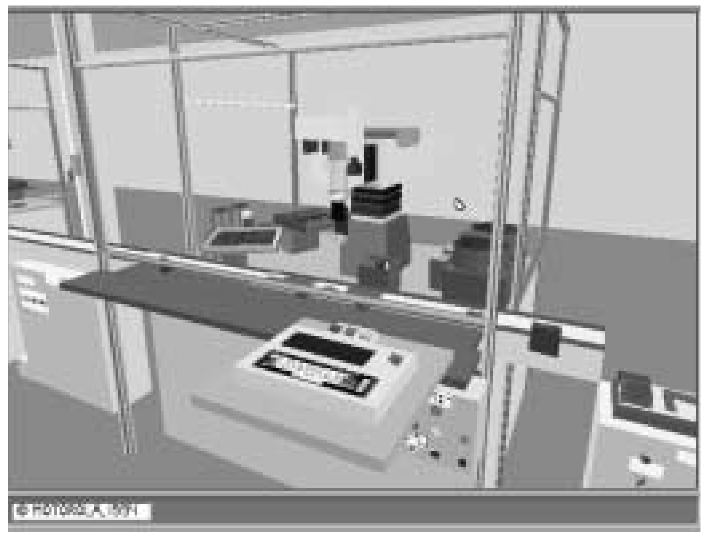
Finally, Adams was concerned that the computers available to create and run the Pager Line model would not be fast enough. Most of the modeling and programming was done on 486/66 systems, and training was done on 66 MHz Pentiums. The Pentium-based systems provided only about 10 FPS when the training was done, but this proved adequate. Adams told us that any frame rate over five frames per second was considered acceptable by the staff and students. Head-mounted displays were supplied by General Reality.

Evaluation

A highly significant aspect of this program is that it is the first evaluation of VR training we know of that tested the training results against a control group. Several caveats must be taken into account when considering these early results. First, and most importantly, the training groups were small, a total of 21 people divided into three groups of seven. Secondly, the evaluation primarily measured errors, and the results show that any of the training procedures provide good results, with a very small number of errors. Finally, there has not yet been any attempt to duplicate these results, which will be essential to prove the overall value of the system. However, with those caveats in mind, we find interesting and probably significant results.

Each group was taught by the same Master Instructor. Everyone had the same classroom instruction. The two VR groups each had 20 minutes of navigation instruction and familiarization, so they could move easily in the virtual lab.

The control group spent one hour in the real lab. With the help of job aid checklists, they worked through the procedures on the real equipment. The instructor was nearby to answer questions. The Desktop VR group used the virtual lab, which they saw on monitors, and used a 2D mouse for navigation. The HMD VR group used the same virtual lab, but saw it in their HMDs. They also navigated using 2D mice. The VR groups also had one hour for learning in the virtual lab, with an instructor and checklists. Following the familiarization time, each person individually went into the real lab, and without the checklists performed the procedures under the eye of the instructor. Each student was graded on the number of errors and missed steps.



One of the robot assembly stations on the virtual Pager Assembly Line. The keyboard is operative, as are the other controls. © 1994 Motorola

HMD Tests Best

Paton knew he had a winner when he saw the students in the VR Groups go to work. They spent more time on any given training task. They were also more focused, he told us, using as a measure the nearly complete lack of conversation among the VR Groups' members. But what was almost unheard of, Paton explained, was that the VR Groups didn't take their allotted breaks; they worked straight through.

Paton and Adams were both amazed at the results of testing. There were three perfect scores: two in the HMD VR Group and one in the Desktop VR Group. Paton told us that the HMD VR Group had essentially no errors (average: 1), and scored in the 80th percentile of all students. (Figure 1.) The total number of errors possible is in the hundreds.

CyberEdge JOURNAL
The World's Leading Newsletter of Virtual Reality

Immersive Best

Continued from previous page.

In only one task did the HMD VR group not score highest. This was the "Running" section, oddly enough, the one considered the easiest. Paton suspects that this was a fluke which will disappear with further testing.

TASK	GROUP: Lab	Desktop	HMD
Setup	13	14	1
Startup	5	6	1
Running	0	0	1
Shutdown	6	4	1

Figure 1: Average Errors per Student

Lessons learned

Adams and Westgaard told us that everyone involved learned a lot on this project. They believe that an input glove would have improved the level of interaction, and hope to evaluate that possibility later. Everyone emphasized the value added by sound. As Paton said, " a key component of model our was audio (currently not spatialized) cues." Adams told us that she quickly came to appreciate the importance of a mix of skills in the project team, including video, still photography, audio, measurement, subject matter, and more. A surprisingly large amount of time was devoted to modeling. They did all the modeling from scratch, as no models were available for the line equipment. To remedy that problem, Paton expects to start working with manufacturing equipment vendors, with the objective of using their existing CAD data to accelerate the modeling process.

The small sample size is a major concern. Paton expects to use the Virtual Pager Robotic Assembly Facility to test another 100-200 people. He will then evaluate the results with this larger sample, to determine if the preliminary results hold up. If they do, Motorola will deploy virtual labs throughout the company, modularizing them and customizing them for each particular work situation. Should everything test out positively, Motorola may even provide VR systems to the technical schools that provide many Motorola employees, so that those new hires will be familiar with the shop floor from day one. Work is expected to continue next year. Imagine the productivity benefits of having new workers actually turning out goods on their first day on a new job. Motorola can.

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