A Welding Cell with Its Own Web Site†

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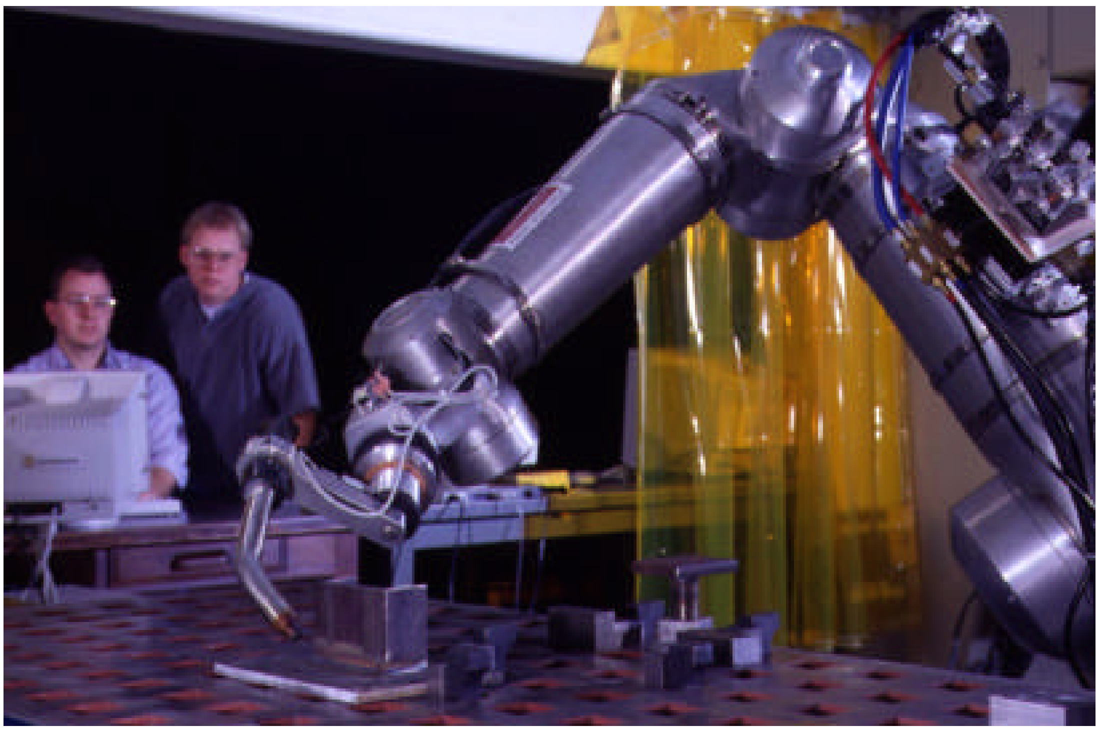
An automated welding cell takes advantage of Internet technologies to reduce downtime and save travel time for the people who design and maintain it.



Communications technology is allowing weld engineers to interact in the operation of a welding cell from a distance, as if they were physically present. The remote engineer can look at the weld, "watch" the robot motion, read front panel displays, and graph files of logged data. The idea is simple – exploit the advances in Internet technologies and put a welding cell on line. The cell that the National Institute of Standards and Technology (NIST) developed sends images of the weld, welding sensor data, and robot-torch position to the remote engineer and allows him or her to

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videoconference with the operator. The remote engineer can be at the other end of the plant or on the other side of the world. Because the techniques take advantage of commercial Internet technologies, the additional equipment in the cell is relatively inexpensive.

Troubleshooting a Weld Cell

The automated welding cell is in Flint, but the group that designed the tooling for the cell is in Milwaukee. The integrator who put the cell together is in Cleveland, but the engineer who selected the welding process parameters is in Detroit. The welding technician who is responsible for that cell is also responsible for six others like it in an automated line 500 m long. The cell operators oftentimes lack the experience or the authorization to investigate process problems: they can only alert others when something goes wrong. If the cell goes down it can bring the entire automated line with it, and that can cost on the order of $1,000 per *minute* in lost production while people in Flint, Milwaukee, Cleveland, and Detroit scramble to get it running again. With the economy growing faster than the supply of skilled workers, there are often not enough trained people who can design, operate, and maintain automated production welding cells.

So how can a few people be in many places at once? The welding group in the Materials Reliability Division and the automation group of the Intelligent Systems Division, both divisions within NIST, have teamed with several industrial partners to address this problem. Guided by input from Caterpillar, Delphi Automotive, Impact Engineering, and members of the AWS-A9 standards committee, NIST has developed a networked welding cell. Funding for the development came from NIST's National Advanced Manufacturing Testbed (NAMT) program, which showcases the utility of high-speed networks in manufacturing.

The NIST Welding Cell

An automatic welding cell was set up at the NIST facility in Gaithersburg, Maryland. A seven degree-of-freedom robot gas-metal-arc welds parts hand-placed in fixtures on a standard welding table. The cell takes advantage of open-architecture implementations developed at NIST for the cell controller, robot controller, and intelligent welding controller. The open, network-based communications structure allows data generated by the controllers to be "copied" and exported from the cell. The cell is also outfitted with cameras and through-the-arc sensing systems.

Remote Access over the Internet

Much of the information sent from the cell is accessed using a general-purpose web browser that connects to the cell's web page. A pan-tilt-zoom camera is mounted in the cell just out of reach of the robot arm. The image is displayed in a web page that can be used to control the camera (Figure 1). The camera can show the weld as it is being made and is useful for post-weld inspection. The server that provides the image for the web page is moderately priced (~$900) but can update the image only a couple of times a second. (Video servers with speeds up to 30 frames per second, TV quality, are now available for roughly twice the price.) The remote engineer can center the camera on any feature by clicking in the image. Zooming is handled using controls on the web page.

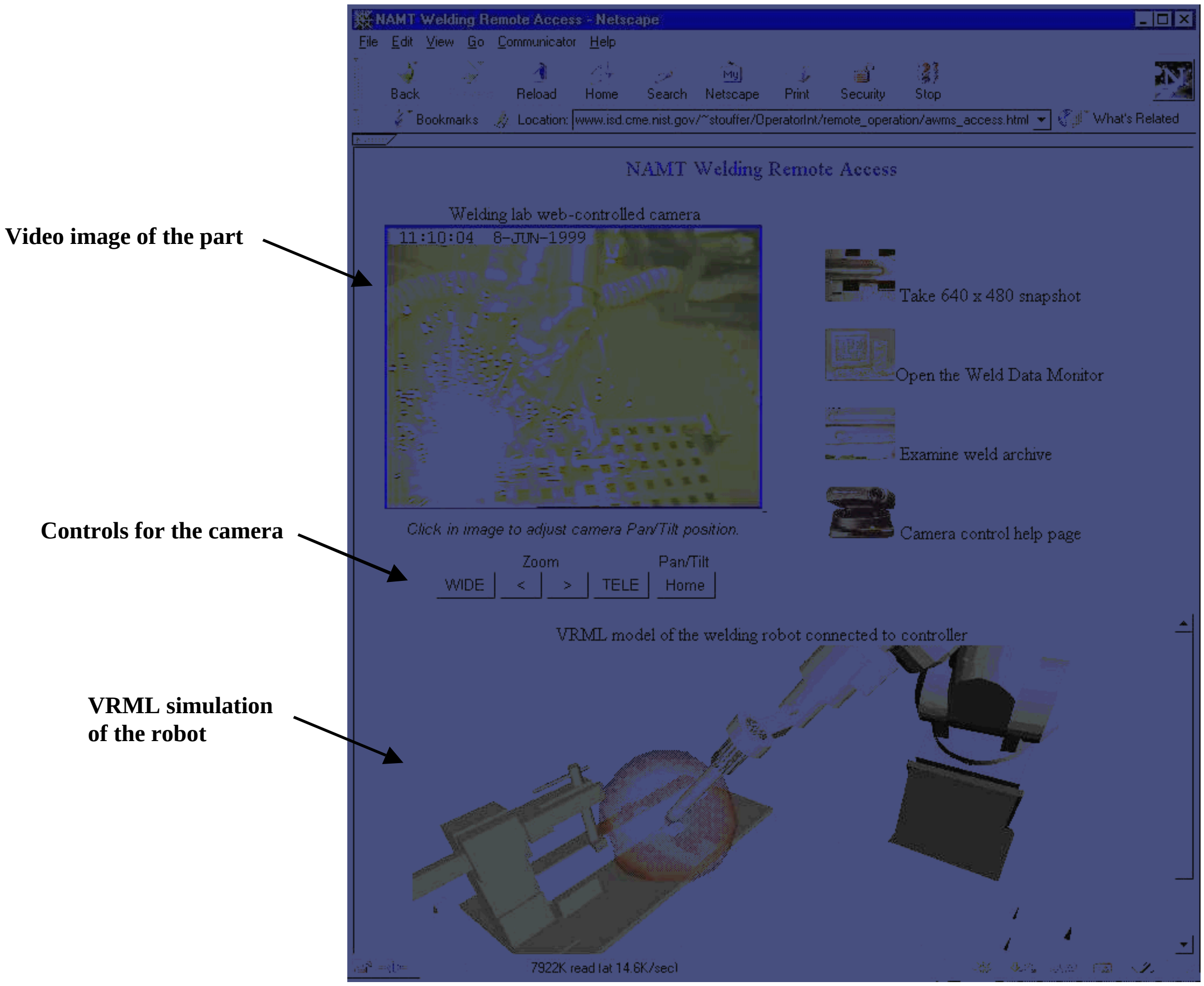

Figure 1: The video image of the part as it is being welded and a solid model image of the robot are displayed on a web page.

To allow the remote engineer to study the motion of the robot, a real-time simulation of the robot motion is also displayed on the web page. The robot controller passes the joint positions to the web server, which constructs a description of the robot in virtual reality modeling language (VRML). VRML is becoming an Internet standard for displaying three-dimensional images, and several VRML programs (plug-ins) are available that can work with browsers to render an image. These programs allow the engineer to view the simulation of the robot from any position as it welds. Viewing the real robot from the video camera might not give the engineer the information needed to detect problems because the view may be blocked by fixtures in the cell or the camera may not be at the appropriate angle. In addition, the current video rate of 2 frames per second is very slow; the simulation updates at close to 20 times a second.

A graphical window displays data that would be read off a front panel display of the welding power source by people in the cell. Figure 2 is strip chart of current and voltage for three different weld segments.

Figure 2: Weld current and voltage are plotted as the weld occurs. This is the same information available on the front panel of the power source.

Another tool for troubleshooting the weld is to combine process data with a solid model of the part. Data for current, voltage, and torch position are recorded by the controller during the weld. After the weld is completed, the graphs of current and voltage are superimposed on a solid model of the part (Figure 3). The graphical display helps operators and engineers quickly identify weld defects with part features instead of having to correlate a time plot of data with robot position. The remote simulation technique uses VRML models, which can be displayed by use of a free plug-in to general-purpose web browsers.

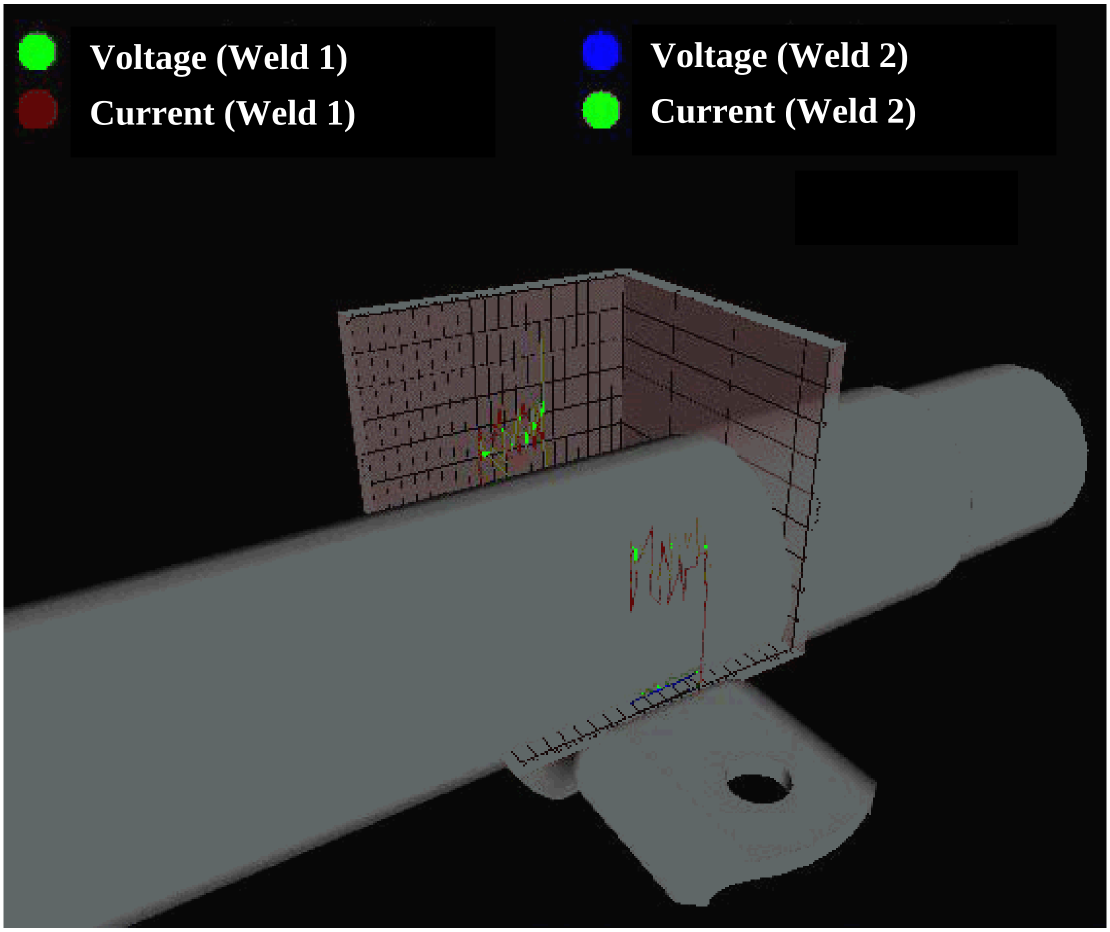

Figure 3: The current and voltage graphs from two different welds superimposed on the solid model of the part. The assembly is a U bracket welded to an automotive strut.

The NIST through-the-arc sensing system (see the supplement of the September 1999 *Welding Journal*), the Arc Sensing Monitor (ASM), was modified to demonstrate how welding data can be made available over the Internet. The ASM calculates seven quality variables and, 32 times per second, decides whether defects have occurred. The ASM is a PC-based system that can be controlled from the network using Transmission Control Protocol and Internet Protocol (TCP/IP), the standard protocols used for the Internet.

In order to get the data to the engineers desk, a scheme was devised that takes advantage of standard commercial database programs. A database server runs a program that connects to the ASM located in the welding cell

(Figure 4). The database server can be anywhere on the network. The program extracts the quality data from the ASM and pushes it into a standard database. A visualization program (Figure 5) (written in Java™‡) runs on the remote engineer's workstation either in a browser or as a stand-alone application. The visualization program connects to the database via a web server. The program allows the engineer to plot a time history of any of the quality variables and to examine which welds have defects. Because a standard, commercial database is used, common office-productivity software can be used to access the database directly.

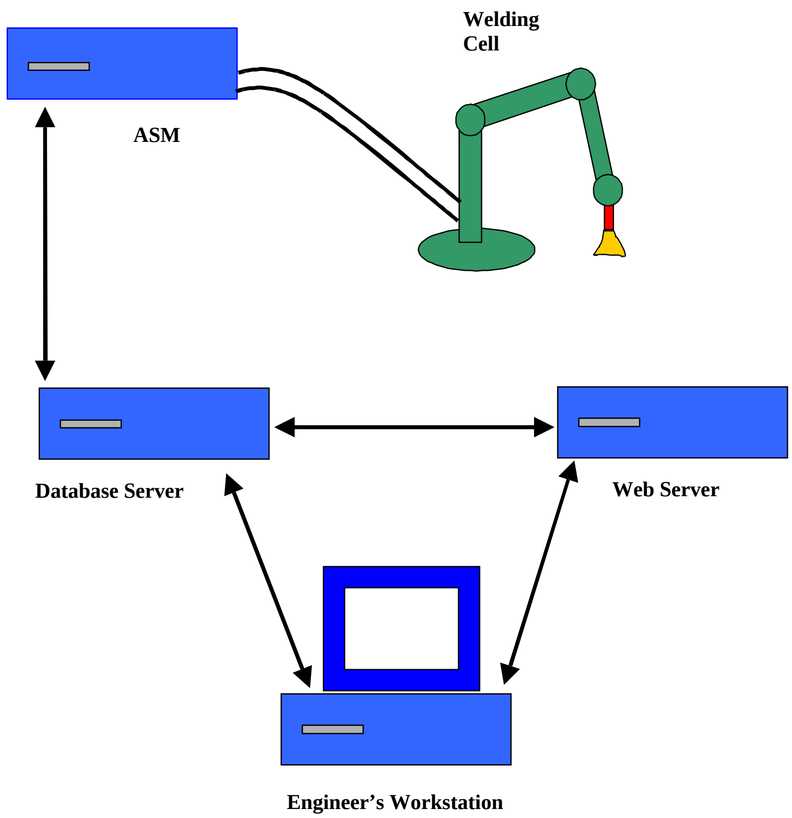

Figure 4: The architecture for conveying welding data from the welding cell to the remote engineer's desktop.

‡ Trade names are used only to specify adequately the techniques used. Such identification implies neither endorsement by NIST nor that the particular technique is the best available for the purpose.

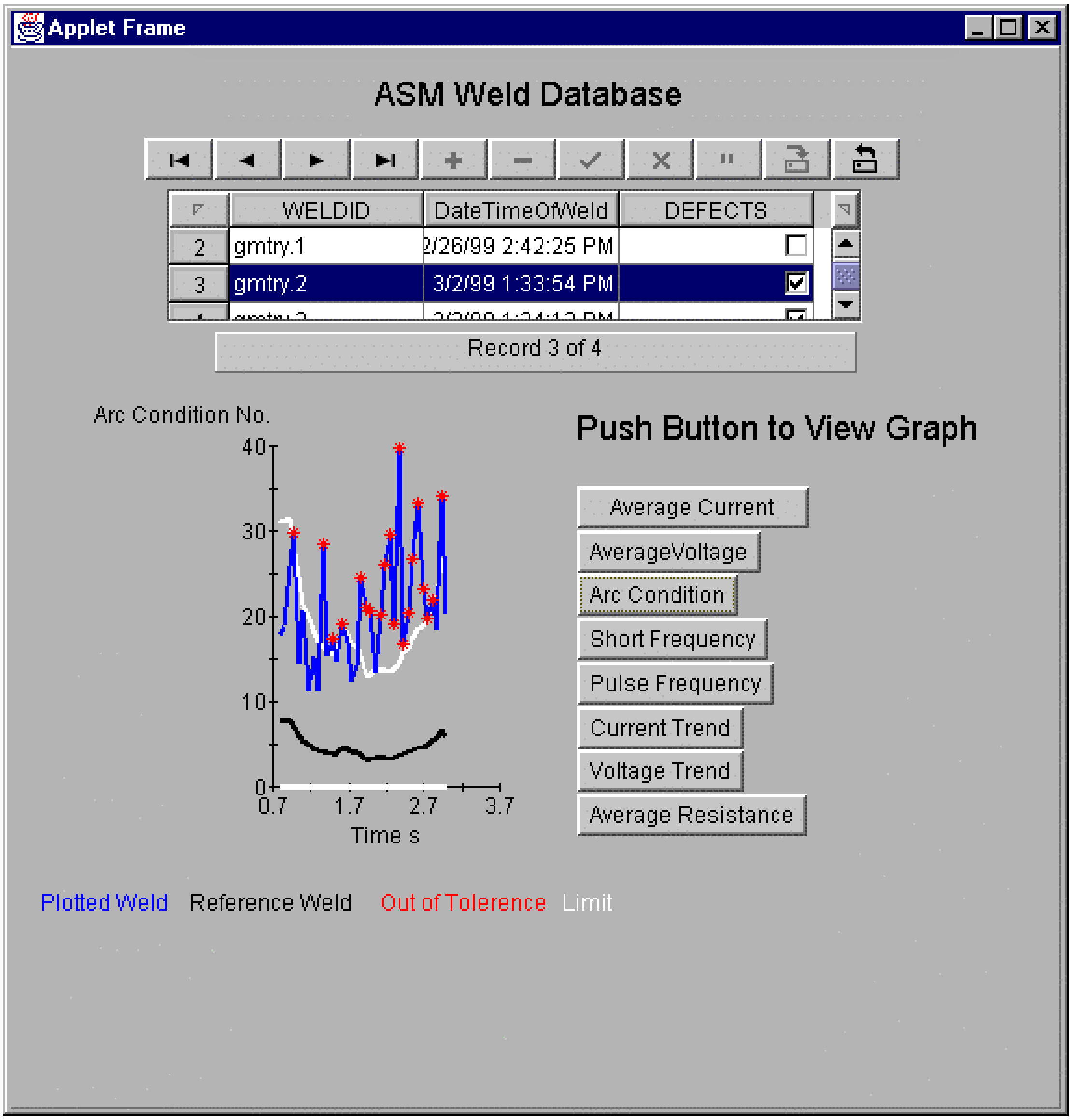

Figure 5: The visualization program allows the remote engineer to plot the data from each weld and to spot trends in the cell's welding performance.

Finally, the remote engineer can videoconference with the cell operator using inexpensive (~$100) cameras and free software.

What is Needed for Remote Access

The equipment needed for remote access to the cell is a pan-tilt-zoom camera (price starting at approximately $1000), a camera server ($900), and a computer to act as a web server and database server. The NIST testbed has two through-the-arc sensing systems, one research and one commercial, which can be accessed over the Internet. Most of the software (web server, database server, VRML viewer, etc.) can be downloaded either free or at low cost over the web. Software written by NIST for web-page controls is also freely available.

Future Developments

The open-architecture controllers used in the weld cell allow simultaneous access in real-time to the current and voltage data as well as the joint position data of the robot. This capability is unique to the NIST welding cell. However, the AWS-A9B subcommittee is working on a standard (A9.4) entitled “A Specification for Data Structures and Protocols for the Exchange of Intra-Cell Welding Information” that if adhered to would allow access to this information in commercial products by the web server.

In the near future, a directional microphone will be installed so that the remote engineer can hear the arc. In addition, work is being done to increase the video rate from the web camera and store the video sequence of each weld in the database. As the AWS-A9B committee adopts the intra-cell communication standard, the standard will be implemented in the cell. Further, we will identify needs for protecting the security of data conveyed over the Internet as well as possible solutions for manufacturing facilities.