A Welding Cell That Supports Remote Collaboration

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Abstract
Discrete part manufacturers using robotic arc welding cells often have several more geographically distributed plants than welding experts. This ratio often leads to costly downtimes due to both logistic and communication deficiencies between weld engineers and the production site. The ability for engineers to remotely access welding cells from their home office to anywhere in the world can yield several benefits. These include quicker response time to problems, improved weld quality, increased production line reliability, and reduced travel time for weld engineers. We describe the NIST testbed technology and infrastructure for remote manufacturing that has been applied and demonstrated on a robotic welding cell where valuable process data can be made available to remotely located engineers in real-time or near real-time.

Remote access to cell information is made possible by open-architecture interfaces that tie the robot controller, weld controller, and cell controller together. The welding cell allows remote access through the internet via: an audio/video system for communicating with the operator, a pan/tilt/zoom camera inside the welding cell for viewing the cell in operation and inspecting parts after a weld, a real-time display for welding process data, a web-based graphic simulation of the robot arm driven by real-time motion commands, and an intelligent monitoring system with an internet accessible welding database. The cell incorporates multiple weld monitoring systems with data logging capability to capture process variables during a weld.

Keywords
weld cells, monitoring, remote collaboration, World-Wide-Web, internet, weld sensing, interface specifications

INTRODUCTION

Discrete part manufacturers using robotic arc welding cells often have several more geographically distributed plants than welding experts. This ratio often leads to costly downtimes due to both logistic and communication deficiencies between weld engineers and the production site. The ability for engineers to remotely access welding cells from their home office to anywhere in the world can yield several benefits. These include quicker response time to problems, improved weld quality, increased production line reliability, and reduced travel time for weld engineers. The NIST testbed enables remote collaboration by providing access to the weld cell information via the internet. The data can be accessed remotely with close to the same ease an on-site.

Data produced by cell controllers and dedicated weld monitors can be accessed and displayed over the internet using a combination of general purpose web browsers and special-purpose programs. The welding cell allows remote access through the internet via: an audio/video system for communicating with the operator, a pan/tilt/zoom camera inside the welding cell for viewing the cell in operation and inspecting parts after a weld, a real-time display for welding process data, a web-based graphic simulation of the robot arm driven by real-time motion commands, and an intelligent monitoring system with an internet accessible welding database.

The cell incorporates multiple weld monitoring systems with data logging capability to capture process variables during a weld.

WELD CELL ARCHITECTURE

Figure 1 shows the current architecture of the NIST Gas Metal Arc Welding (GMAW) cell. Three controllers form the framework of the cell: a robot controller that controls the robot, an intelligent welding controller that controls the welding process, and a cell controller that oversees the welding cell and interprets the weld program. Other elements of the architecture deal mostly with monitoring sensors and storing weld data.

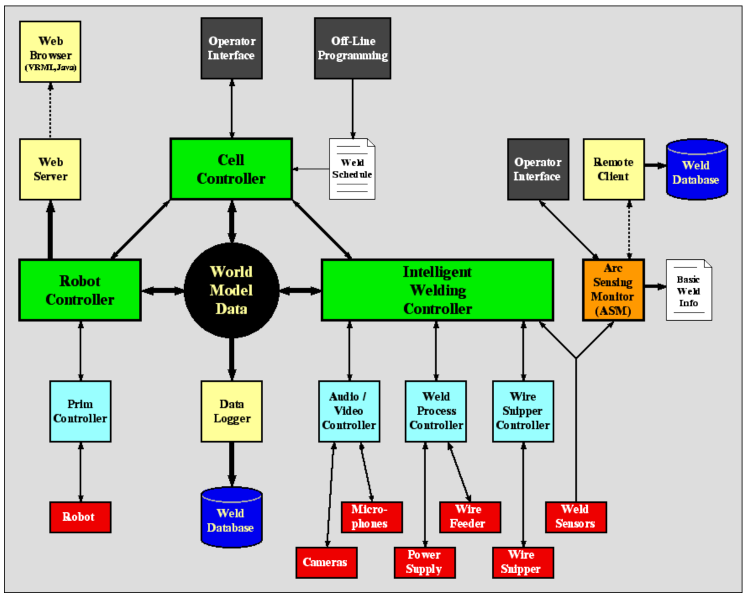

Figure 1 - NIST GMAW Cell Architecture

The **robot controller** controls the robot joint actions to produce the commanded torch path and orientation. The robot controller also makes some of its internal control data available to the World Model [1] and to a web server though open architecture interfaces. Real-time torch location and orientation data is useful when combined with weld process data to relate weld process variables to part geometry.

The **intelligent welding controller** has three sub-controllers: the audio/video controller, the weld process controller, and the wire snipper controller. The audio/video controller handles the microphones and cameras for observing the weld from remote locations. The weld process controller operates the welding equipment to produce the desired weld. The wire snipper controller trims the welding wire to a known length. Through-the-arc sensors feed weld process data back to the intelligent welding controller.

The **cell controller** supervises the welding cell. It interprets the weld program and sends commands to the robot and intelligent welding controllers and monitors their status. It also handles the operator interaction. All commands from the user to cell components go through the cell controller.

The other cell elements monitor sensors and log data to local files. The world model data consists of all data in the welding cell that is shared between controllers and elements. These include torch position, arc voltage, arc current, error states, etc. The data logger accesses all of this data and stores it in local welding data files.

Monitoring Systems

Monitoring systems gather sensor data at high rates (1-10 kHz), and at minimum, store the data. Filtering and averaging calculations reduce the amount of data that needs to be supplied to other systems, both in real-time and in database files. Some monitors compare real-time data to limits and report alarms when the limits are exceeded. The primary sensors used in weld monitoring systems measure arc voltage and current. Additional sensors may measure wire feed speed, shielding gas flow rate, coolant flow, etc. Data from these sensors are used to model weld quality.

The NIST GMAW cell architecture in Figure 1 shows weld sensors that feed into an embedded monitoring system. NIST's monitoring system uses arc voltage and current sensors to determine weld quality. The voltage sensor is attached to the power supply output terminals. The current sensor is a hall effect current transducer surrounding the electrode cable.

We also incorporate two standalone monitoring systems into our GMAW cell: the Arc-Sensing Module (ASM) [4] developed by the Materials Reliability Division at NIST, and the ARCAgent-2000 [2] developed by Impact Engineering . Both systems measure voltage at the power supply output terminals. The ASM uses the same hall effect sensor data as the embedded monitoring system, but the ARCAgent uses a current sensor in-line with the power cable. The ARCAgent-2000 also has the capability to use wire feed speed and gas flow sensors, but neither is used in this implementation.

While a weld is being performed, the embedded system records voltage, current, and torch position. The ASM records voltage, current, and time. After the weld has been completed, it computes a modeled arc quality index. The ARCAgent records voltage, current, and time. It filters the data and produces average values and analysis of the electrical characteristics of the weld such as pulse frequency and average voltage.

All three monitoring systems store their data to their own respective files. These files can be stored and retrieved at a later time if a particular weld needs to be analyzed. Currently all three are implemented on different PC platforms and store to local disks. A near future issue is to improve the integration of these files.

DISCLAIMER: Certain commercial equipment, instruments, or materials are identified in this paper to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

Intra-Cell Communications

Real-time communications between processes in the cell employ a NIST communications utility called the Communications Management System (CMS) and a software API called the Neutral Message Language (NML). [9] CMS uses a shared memory model of communications that has been implemented over many different media, including shared memory, dual port RAM, and ethernet. NML is a software interface that utilizes CMS communications, allowing a user to send messages between software modules easily. In addition to allowing intra-cell communications, NML also allows servers to access the data from anywhere over the internet.

Internet Interfaces

Figure 2 shows how the welding testbed interfaces to the internet. The pan/tilt camera is a commercial product that has an embedded web server. It exports images at about 1 Hz, and can accept aiming and zooming commands. A web-based interface to the server is used to communicate with the weld cam. Anyone on the internet running a general purpose browser can view images and control the camera. Figure 3 shows a top view of the welding table and robot arm with torch.

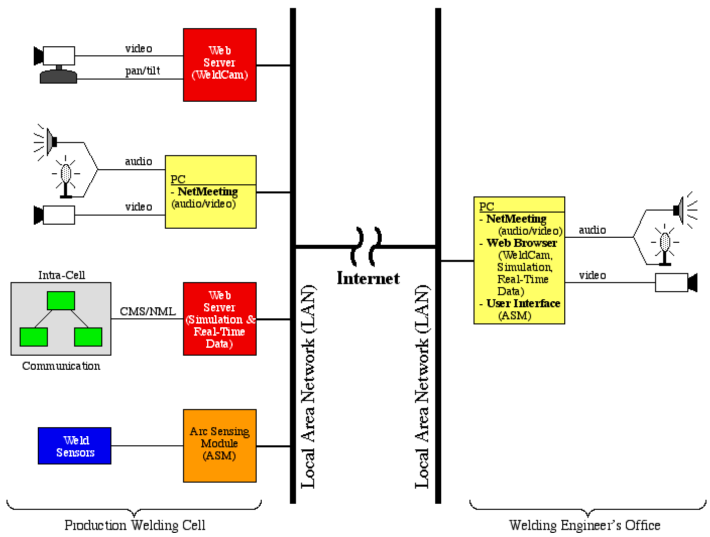

Figure 2 - Internet Interfaces to the NIST Welding Testbed

The stationary camera is attached to a low cost commercial video board. NetMeeting software from Microsoft integrates video from the board and audio from a microphone. Two way communication is possible with someone else anywhere on the internet via NetMeeting.

The cell web server connects to the intra-cell NML interfaces, and makes their information accessible. This allows internet processes to read intra-cell data using TCP/IP protocol. Typical data rates are 20 Hz for torch position and process data.

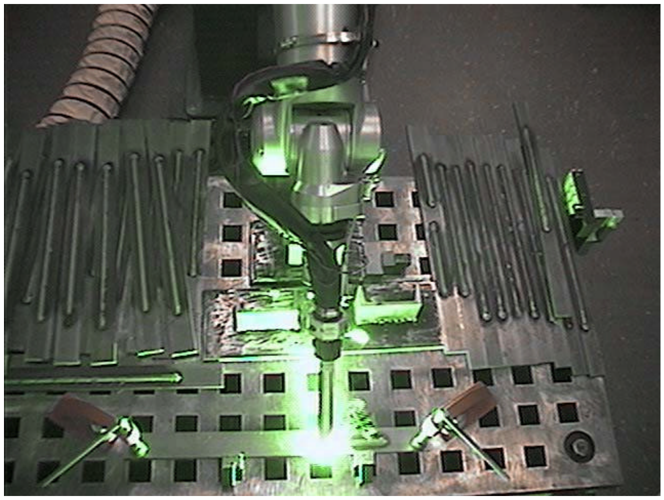

Figure 3 - Live Video Feed from Weld Camera

The Arc Sensing Monitor has a custom interface to the internet that employs TCP/IP socket protocol. The remote user interfaces to this custom interface, allowing them to download a database of welding information. This weld database contains raw sensor data as well as processed data such as weld quality and estimated pulse frequency. Due to the ASM's custom interface, it is not possible to access the weld database through a general purpose web browser at this time.

Figure 4 - JAVA Strip Chart Graph

The embedded monitoring system has added capabilities to remotely access to the data. While a weld is being performed, the system allows the process variables to be remotely viewed in real-time with a JAVA strip chart graph as seen in Figure 4. This graph shows real-time data that can give an experienced welder a feel for what is happening with the weld as it is being performed.

NIST has also developed technology to overlay recorded process data onto a three dimensional model of the part to give the operator a better view of where possible defects may have occurred. Figure 5 shows an automotive strut part with voltage and current displayed as lines in a 3D plot. This display is possible due to sharing of data between the welding and robot controllers and the synchronization of the two data streams by the cell controller.

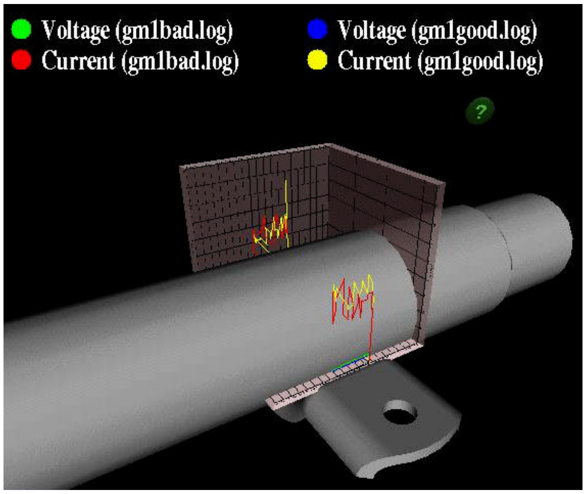

Figure 5 - VRML Plot of Voltage & Current Overlaid on Part Geometry

All of the above technologies discussed above can be seen at the project web site http://www.isd.cme.nist.gov/projects/awms/ .

REMOTE COLLABORATION SCENARIO

A weld engineer establishes audio and video communications with operators at the welding cell. The weld engineer can remotely examine ASM settings and change them if needed. The engineer operates the weld cam to survey the cell, and to see close up views of the part to be welded, fixtures, robot torch, etc. The engineer readies the ASM for monitoring and the operator initiates a welding sequence at the cell. The audio link allows the engineer to hear the weld at reduced fidelity due to bandwidth limitations. The engineer watches the strip chart display for instantaneous voltage and current and the robot simulation for robot motion and process events.

The engineer operates the weld cam to get a close up view of the completed weld. He connects to the ASM and downloads the weld data for the completed weld. The ASM remote program enters the data in the database and filters it to detect events and to model weld quality. The engineer and shop floor operator discuss the results of the experiment, and decide to try a new test. The interactions of the engineer and operator occur almost as if the engineer was on the shop floor.

NEXT STEPS

NIST will be looking into internet security issues of remote access to welding information. Proprietary information that may need protection from remote access includes CAD data for weldments, video data, weld programs, and data from the completed welds.

In the near future, we will pursue the following issues to improve remote capabilities:
- Increasing video frame rates for internet images;
- Automating audio and video recording;
- Synchronizing data streams from different controllers and monitors;

- Centralizing world model data acquisition to simplify interfaces for external access;
- Integrating the testbed with higher level collaborative tools [10];
- Automating co-display of part geometry and sensor model data (Figure 5);
- Incorporating the commercial monitor in remote access, either by adapting interfaces ourselves or using modifications made by the vendor;
- Exploring standard interfaces both for integration of cell components and for remote access;
- Editing the weld program remotely; and
- Initiating cell events, like cycle start, remotely.

NIST is working as a member of the AWS-A9 committee on Computerization of Welding Information to develop a specification for the exchange of welding information between intelligent systems. The NIST testbed will be used to test specifications while they are still in draft stages. One current working document is the Arc Welding Activity Model (available at http://www.isd.cme.nist.gov/projects/awms/aws/).

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