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Programmable Automated Welding System (PAWS): Control of Welding Through Software and Hardware

Martin D. Kline
Project Manager
Babcock & Wilcox
CIM Systems
Lynchburg, VA

Thomas E. Doyle
Technical Advisor
Babcock & Wilcox
Alliance Research Center
Alliance, OH

Introduction

The first programmable control units for welding involved only the regulation of the welding power and travel speed usually performed by setting manual knobs and limit switches. The next generation of controllers then evolved as welding package extensions to commercial robot controllers. This second generation provides much greater capabilities such as, procedural language support (logic statements, sub-routine calls, etc..), control of complex manipulators, seam tracking, and the programmable control of the welding power supply. These controllers remain, however, hampered by complications with interfacing with other equipment (sensors, networks), limitations with processor performance, and a lack of flexibility. In addition, due to their nature, these controllers are more capable at the programming of the manipulator's motions than the integration of welding and motion attributes. This mode of operation provides adequate capabilities in medium- to large-batch operations where one of several pre-planned part programs are selected at the stand alone workcell.

The demands of very small batch operations and the need to integrate into a wider automation strategy have pushed the development of the present state-of-the-art controllers. These controllers address the integration of both off-line planning and real-time control activities. One such advanced welding control system is under development by Babcock & Wilcox. This system was initially developed as an Advanced Technology Development contract with the Naval Surface Warfare Center, Carderrock Division industrial transition is now being performed under a ManTech contract as part of the Navy Joining Center. This system, known as the Programmable Automated Welding System (PAWS), was created specifically to provide an automated means of planning, controlling, and evaluating critical welding situations to improve productivity and quality. The Navy was primarily concerned with the declining availability of skilled welders and increasingly difficult welding situations.

This system is capable of acquiring input from multiple process sensors and integrating this information to produce high quality welds with limited operator intervention. This challenge demanded a high-level of processing performance, a simple, yet flexible, operator interface, and a focus upon welding-specifics.

System Overview

PAWS consists of an Off-line Programming System (OLP) and an on-line, real-time controller. The OLP system provides a means to develop the plan for an entire automated welding operation, as well as the capability to manage existing plans. The OLP system provides an integrated platform for the motion and process planning functions. The Controller is capable of then implementing these plans during the actual welding process.

PAWS Off-line Programming System

The OLP system resides on a UNIX-based workstation and is comprised of a relational database, a motion planning module, a geometric modeling system, and a job builder module (refer to Figure 1). This system was developed following a client-server philosophy specifically to provide a decision support tool for the development, storage, and management of programs for the PAWS controller. The use of standards and the requirements of hardware portability have been highly stressed.

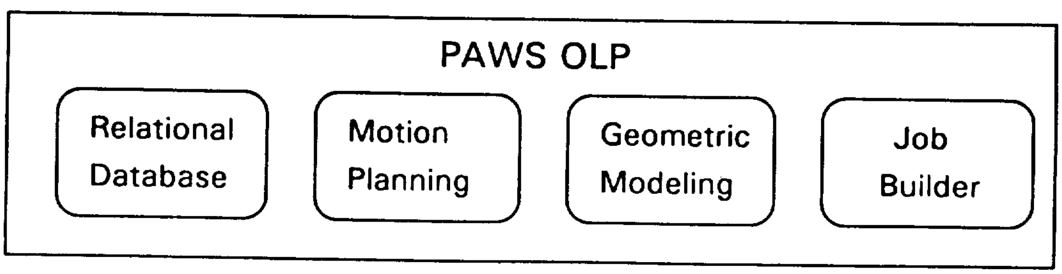

Figure 1: PAWS OLP

Relational Database This module provides a standard, user-friendly procedure for the generation and storage of strategies and information for performing the welding operation, these include welding process data, sensor fusion priorities, error resolution tactics, parameter logging plans, and I/O control actions. Storage of certified welding procedures in a standard database format allows for the maintenance and re-use of previously performed welding trails. This can significantly reduce the effort required to develop new certified weld procedures and weld schedules.

Motion Simulation The motion simulation module ties the motion of the manipulator to the process information. This module provides a graphical 3-D animation of the manipulator performing the welding operation with real-time collision detection. The interface for this process allows the operator to select joints for welding, to assign to each joint a welding plan, to plan non-welding motion paths, to establish the orientation of the welding torch to the joint, to assign program attributes to physical part locations, and to re-plan motion in the event of a detected collision.

Geometric Modeling This module provides a convenient method for the modeling of parts, manipulators, end effectors, or physical environment constraints. This system also provides a means of importing CAD files of components and generating solid models from those files.

Job Builder The last subsystem, the job builder module, converts the plan into the PAWS controller-specific format to provide true off-line programming of the entire welding operation. This data is provided to the PAWS controller in the form of text files which are then converted to the real-time database format.

PAWS Controller

The PAWS controller consists of a VME Backplane with multi-tasking 68040 processor boards dedicated to welding and sensor control. In addition, a third 68040 processor provides the motion control, operator interface, and process coordination capabilities. On-bus resources provide the interface to the process equipment, including servo motion boards, as well as, digital, analog, and system I/O boards.

The PAWS controller accepts the plan from the PAWS OLP system and is capable of both on-line modification of this plan, as well as, the generation of an entirely new plan. The system uses a database structure to compartmentalize the process data. The controller is divided into modules which can be selectively employed to address the specific application (refer to Figure 2).

Process Coordinator The coordinator module utilizes a sequencer, to indicate the data which each process module should use for execution, and a rule-based expert system for exception handling. The sequence is built-up (either manually on the controller or automatically by the OLP's job builder module) as a series of statements specific to the welding process. These statements are English-like commands (e.g. START WELD ARC, STOP WELD ARC, MOVE ALONG, LOG DATA, etc..) which a provide readable, high-level view of the job plan. During execution, the exception handler monitors the state of the on-going process and issues programmed responses when anomalous conditions occur. These responses can range from simple warnings to complex adaptive responses.

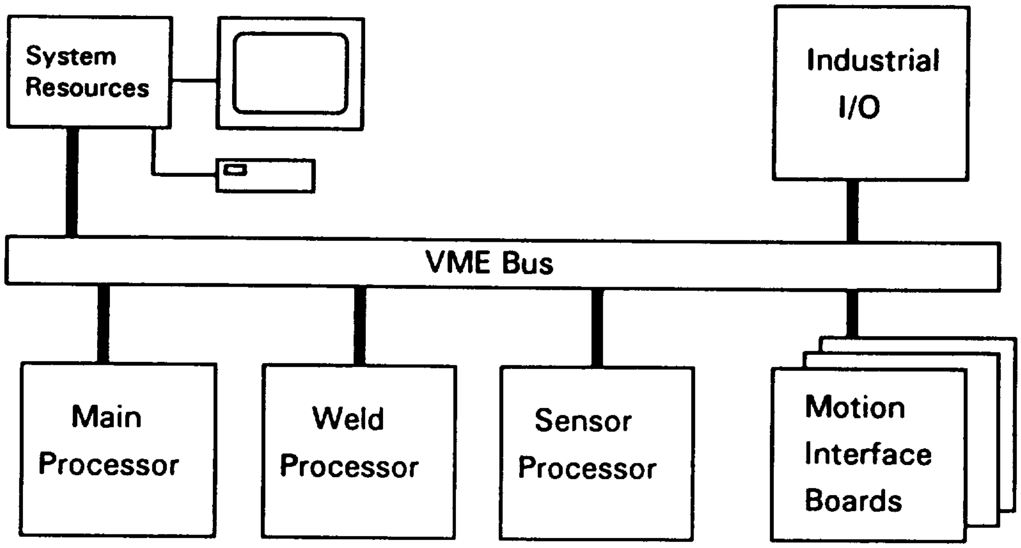

Figure 2: PAWS Controller Architecture

Motion Control The PAWS controller is capable of controlling a variety of manipulators, from a simple 3-axis tractor-type welding device up to multi-axis robotic manipulators. A total of three manipulators and 32-axis may be controlled from a single controller. The current demonstration system is based upon both a 6-axis PUMA 762 with a 7th oscillator axis and a separate 4-axis track device. The initial phase of the transition program will include the establishment of a teaching factory at a Babcock and Wilcox facility. This teaching factory is intended to include a gantry robot.

The motion control module incorporates the ability to perform path memorization, for the welding of passes which have been partially completed and are difficult to seam track Additional features include: seamtracking, the ability to accept operator overrides of both cross seam and standoff distances, the ability to modify motion parameters (including oscillation parameters) for adaptive control, and the ability to perform touch sensing of the weld joint.

Weld Control The weld control module commands the power supply to control the weld process. The demonstration process is the synergic gas metal arc process (S-GMAW). The module commands the current and the voltage trim while monitoring a number of process parameters. Process parameters are prevented from exceeding the limits established in the weld procedure.

Parameter modifications are received from both the sensor control module and the operator interface and are implemented by the weld control module in a coordinated fashion. An embedded rules engine is employed for exception handling. Additional features include, consumable tracking and monitoring, user-definable I/O, and the expandability to other processes.

Operator Interface All interaction with the operator is performed through a menu-based graphical user interface. This interface provides both the run-time monitoring and reporting functions, as well as, the on-line teaching and planning features. Multiple window capabilities enable the viewing of data which is being logged, the monitoring of all system events, warnings, and errors, and the real-time monitoring of sensor data.

Parameter Logging The parameter logging module allows for the selective logging of data based upon time, path length, event-occurrence, or the reaching of an established threshold (e.g. heat input). Parameters can be also be averaged while being logged. Post-weld analysis capabilities allow logged data to be trend charted, as well as, the plotting of X-bar and R charts.

Sensor Control The last module to be discussed is the sensor control module. This module provides the corrective control algorithms for adaptive control and the fusion algorithms for dealing with the complicity of data provided by the numerous process sensors. The PAWS program incorporates the use of eight different sensors (see below). This module performs user-programmable data filtering, adaptive control of the welding process, and interfaces with the motion control module for joint finding and tracking. Exception handling is performed by an embedded rules engine. The current demonstration system performs communications with the various sensors through a dedicated serial port. Future implementations will incorporate a number of means including network protocols and backplane communications.

SENSOR	USAGE
Joint Vision Sensor	Seam Tracking Joint Volume Joint Shape
Integrated Optical Sensor	Pool Width Bead Height
Arc Element Sensor	Contamination in Arc (H_2, O_2, Fe)
Through-the-Arc Sensing	Seam Tracking
Touch Sensing	Joint Location
Arc Sensor Module	Arc Electrical Performance
Weld Acoustic Monitor	Arc Acoustical Performance
Plateborne Acoustic Emission Sensor	Defect Count Defect Type Defect Location

The Joint Vision Sensor is a commercially supplied sensor, whereas each other sensor has been developed within the PAWS program. The Idaho National Engineering Laboratory (INEL) developed and supplied the Integrated Optical Sensor. The National Institute of Standards and Technology (NIST) developed the Arc Sensor Module. The David Taylor Research Center developed the Weld Acoustic Monitor. Babcock & Wilcox has developed the Arc Hydrogen Sensor and the Plateborne Acoustic Emission Sensor.

The listed sensors cover a wide range of control areas including feedforward, feedback, and process monitoring. The PAWS controller is, however, capable of being configured to utilize only those sensors which are needed to perform the particular application. A typical application which is severely space-limited may use only through-the-arc tracking, whereas, an accessible component with critical process control criteria may utilize five or six different sensors.

Summary

The ATD phase of the PAWS program ended in November 1992 and the follow-on ManTech program was started in September 1993. The system will be industrially hardened during the first year of this program. Follow-on years will focus upon the transition into specific end-user sites. These implementations will also expand the system into other welding processes (e.g. FCAW, GTAW, PAW). In addition, the architecture is being developed for application to other non-welding robotic processes (e.g. inspection, surface finishing). Future development is anticipated to encompass hardening for extreme environments, expanded exception handling techniques, and application to a range of manipulators.