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FINAL REPORT

Advanced Computer Architecture Specification

for Automated Weld Systems

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I. ADVANCED AUTOMATED WELDING SYSTEM

1. Introduction

In robotic welding, the computerized support of the design and welding processes includes component design and preparation, weld procedure design, and on-line control of the welding power supply and the robot.

An advanced, automated system, capable of welding seams with varying seam cross section and orientation, integrates both planning and real-time control activities. Planning functions include the development of a geometry model and a graphical support system within a standard and portable environment. Real-time control functions include the development of a modular, intelligent, real-time control system and the development and integration of a number of welding process sensors.

An automated robotic welding system has to overcome problems which include an inexact knowledge of the welding process, the lack of a generalized description of the seam, and the control of the many parameters that influence the welding process and the resultant quality of the weld. More specifically, one problem is the difficult work associated with programming welding robots. The frequency of reprogramming is an important factor. A second problem is the shape deviation of the sample to be welded in comparison with the model by which the robot has been programmed.

There are ways to overcome all problems in the design of a automated welding system. The difficulty of reprogramming the robot can be reduced by automating the programming task as much as possible. Accurate workpiece processing and fixation can solve the shape deviation problem. Another, more general and inexpensive way is to use automatic sensing for the detection of deviations between the workpiece model used for programming and the physical workpiece. The detected deviations are then used to adjust control variables in some predetermined way and in accordance with an appropriate strategy.

2. Overview

The design of such an automated system demands increased processing performance, better process control, a simplified, but flexible operator interface, and

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an understanding of welding specifics.

The basic principle of the system is that a workpiece to be welded is designed using a CAD system. A control vector is defined to contain path coordinates, welding variables and reference workpiece geometry data. Such a vector and its trajectory is generated by off-line programming, based on models of the welding process and the CAD model of the workpiece. The reference data are then used to perform the sensor controlled robotic welding process. The actual workpiece geometry is measured with sensors. Features of interest are extracted and compared with features generated from the CAD model of the workpiece. The shape deviations are identified and compensation of the off-line generated control vectors is performed, such that some predetermined welding quality criteria can be satisfied.

The system must contain an off-line programming system and an on-line, real-time controller. The off-line programming system provides a means to develop the plan for an entire automated welding operation, as well as the capability to manage a database of existing plans. The real-time controller is capable of implementing these plans during the actual welding process.

2.1. Off-line programming

An efficient and natural design procedure is to use solid model representations for the components to be welded. This enables the components to be specified as combinations of solid primitives and to be manipulated as complete entities, and allows access to the low-level component representation. It also makes possible the definition of the intersection curves. The solution of the surface intersection problem provides a direct link to both off-line torch trajectory planning, and the specification of the required joint preparation. The intersection curve that defines the seam to be welded, as well as the desired torch position and orientation trajectory, are also available from the design procedure.

The profile of the seam is determined in a cross section perpendicular to the modelled welding seam. The profile is used to generate the number of layers and the number of passes of each layer, necessary to satisfy certain geometrical welding quality criteria. Then, a trajectory of a control vector is generated based on a

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geometry model of the seam to be welded. Also estimates of the deposition rate as a function of position should be provided.

An off-line programming system can reside on a UNIX-based workstation and contain a relational database and modules to perform motion planning, geometric modeling and schedule building. This system becomes a facility that supports the development, storage and management of schedules for the on-line controller.

2.1.1. Relational Database

The database supports standard procedures for the generation and storage of strategies and provides information for performing the welding operation. Information includes sensor fusion data and I/O control actions, welding process data, procedures for parameter logging, and plans for error resolution. Storage of welding procedures in the database allows for the maintenance and reuse of previously performed welding runs.

2.1.2. Motion Planning and Simulation

This module relates the motion of the robot to the process information. It provides a graphical three-dimensional view of the robot performing the welding operation with real-time collision detection. The interface for this process allows the operator to select seams for welding, assign to each seam a welding plan, establish the orientation of the welding torch to the seam, plan motion paths with no welding activity, and replan motion in the event of a detected collision.

2.1.3. Geometric Modeling

This module provides a method for the modeling of parts, robot and physical environment constraints. It also provides a means of importing CAD files of components and generating solid models from those files.

2.1.4. Schedule Building

This module produces data on the entire welding operation to be used by the controller in the form of databases and text files.

2.2. Real-Time Controller

2.2.1. Control of the Welding Process

Process control should be based on a model of the welding operation. This

model may be used to determine the effect of the parameters which can be directly controlled on the resulting weld properties. Parameters include current, voltage, travel speed and wire-feed speed. Weld properties include width and depth.

A simple model which relates specified parameter values to weld properties, can provide a minimum level of support to the on-line control of the weld process. Since there are always effects that have not been modelled, the controller must minimize the effects of discrepancies between the model and the actual system, on the resultant weld. This requires the definition of relevant weld process parameters, and the development of a higher level (inverse) process model which relates weld parameters to directly controlled parameters. Sensors ahead of the weld area on the workpiece detect the seam geometry and extract suitable weld process parameter values to effect a form of schedule control.

2.2.2. Torch Control

An advanced automated welding system does not suffer from the restriction of having the workpiece clamped so that the seam to be welded is consistently located with respect to the programmed path. Such a system senses the actual seam location and seam geometry ahead of the torch using an optical seam tracking system. This improves the tolerance to part-to-part dimensional variation, and hence the consistency with which the weld is placed on the seam. Torch weave can also be used to accommodate varying seam width. Also, torch travel speed can be controlled to accommodate the deposition rate as a function of sensed gap size. Other parameters such as torch offset and orientation with respect to the seam can also be controlled as it becomes necessary in the application.

An advanced automated welding system contains a seam tracking system to capture structured light images of the seam and provide real-time trajectory control of the torch. Images are analyzed on-line to provide the seam location and the relative position and orientation of the torch. This type of processing requires dedicated image processing and seam tracking processors. This control structure provides the ability to change the vector components at any time.

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2.2.3. The Controller

The controller receives the schedule from the off-line programming system. It is capable of both on-line modification of this procedure and the generation of an entirely new procedure. Part of the controller software is a coordinator module which contains a sequencer to indicate the data which each process module should use for execution. The controller software also contains an expert system for exception handling. The sequence is built-up as a series of statements specific to the welding process. These statements should be English-like commands which provide a readable, high-level view of the schedule.

2.2.4. Motion Control

The controller is capable of controlling a variety of multi-axes robots. It should have the ability to accept operator overrides of distances and the ability to modify motion parameters for adaptive control.

2.2.5. Weld control

The weld control module instructs the power supply to control the weld process. The module monitors the process parameters and commands the current and the voltage adjustments. Process parameters should be prevented from exceeding the limits which have been established in the weld schedule. The weld control module receives parameter modifications from both the sensor control module and the operator interface and coordinate the responses. An embedded rules engine is employed for exception handling. In addition, the weld control module performs tracking of consumables.

2.2.6. 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. Parameters can be also be averaged while being logged. The system should have extensive post-weld analysis capabilities.

2.2.7. Operator Interface

It is important that the operator be able to interact with the system in real-time to adjust the goals of the system. In particular, the operator may wish to

change the welding parameters. In order to do this, the system needs to be aware of this request to determine the impact to the commanded change on the other system goals. The operator is notified of any limiting restrictions. The system should allow the operator to command corrections based on observable welding conditions rather than basic welding parameters. The system should be able to define the parametric changes required to achieve this goal, while maintaining the other process goals.

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.

2.3. Sensor processing

Sensors are classified as feedforward, feedback, or monitor. Feedforward sensor information, such as measuring the location and dimensional properties of the weld seam in advance of the weld torch, is used to supply feedforward control data for the motion and welding modules, and define set points for tracking and welding process control to be implemented once the torch is at the point of measurement. Feedback sensor information, such as weld pool position, pool size, and cooling rate, is used to supply feedback control data for the motion and welding modules. Prioritization is necessary in cases where feedback data from multiple sensors results in conflicting control responses. Monitor sensor information, such as data from the arc hydrogen sensor, is used to check for exception conditions and cause the system to respond when they exist.

The sensor processing module provides the corrective control algorithms for adaptive control and the fusion algorithms for dealing with the complex stream of data provided by the numerous process sensors. It adjusts the welding operation in response to application perturbations and operator adjustments. Additional inputs to the module are data from the operator, database information and coordination information. Incorporation of different sensors, including feedforward, feedback, and process monitoring should be supported. Examples include seam vision sensors,

integrated optical sensors, arc hydrogen sensors, through-the-arc sensing, touch sensing, arc sensor module, weld acoustic monitors and ultrasonic sensors. This module performs data filtering, adaptive control of the welding process, and interfaces with the motion control module for seam finding and tracking. Outputs from the processor are commands to the welding and motion control processes, and event indications for coordination of the controller activities. The data is also provided to other modules in the system for display to the operator and for parameter logging operations. Exception handling is performed by an embedded rules engine. Communications with the various sensors can be performed through serial ports, networks or the backplane. The system should be capable of being configured to utilize only those sensors which are needed to perform the particular application.

The system maintains databases which are accessed in real-time to define which sensors are being used, how the sensors are to be viewed, the sensor data transfer functions and coefficients, sensor configuration data, and event / response relationships. The user should be able to select the sensors to be employed and also define the control response for a given application.

In the case where a number of different sensors is required, a very sophisticated scheme of dealing with the sensor data is required. The sensors can not be viewed as autonomous entities. When considering input from a multitude of real-time sensors, issues such as data arbitration and fusion become increasing complex. In many cases the information from the sensors appears to conflict thereby making it difficult to define a corrective action. The system should be able to deal with the situation of controlling and gathering data from multiple sensors.

II. COMPUTER SYSTEM DEFINITION

The computer system will process welding information.
Welding information consists of following distinct types of data:
1. Attributes of the part being welded.
2. Attributes of the materials used in the welding process.

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3. Welding process data, consisting of the attributes of the devices used in making the weld.

4. Welding device operational data, consisting of functional descriptions and capabilities of the devices used in making the weld.

Computer system capable of supporting a flexible multiaxis motion control welding system.

The welding system consists of welding devices, motion control devices, operator interfaces and the computer system. Each device is controlled by an associated device controller.

1. The computer system coordinates and supervises device controllers. Each device controller controls a specific device : welding power supply, wire feed motor, motion control etc.

2. The computer system can exercise active control. It can direct and regulate the welding process without the need that the operator intervenes. Of course, the operator can always interrupt the process.

3. The computer system communicates welding information with the operator and a higher level computer. It is capable of both sending and receiving information.

4. The computer system locally stores and retrieves welding information.

A computer system with such capabilities can provide multiple benefits.

1. Since decisions are made automatically by the system and not by the operator, the welding process can have much higher throughput.

2. Necessary changes and adjustments during the welding process can be made at a higher speed, since the information that relates to quality performance is available within the computer system. This results in improved quality.

3. Increased number of available alarm signals and speed of alarm reporting results in improved safety.

4. Since the computer system can communicate with higher level computers,

accuracy is maintained, as the operator has no need to perform data input and translation.

5. Reduced need for welding operator training.

6. Reduced waste due to the ability to make fast changes.

7. The user-friendly design capabilities made available through the system and application software result in increased flexibility in setting up new welding procedures.

In more detail, the computer system performs the following control functions :

1. Coordinates the activities of welding and motion controllers.

2. Provides active control and system coordination.

3. Provides the ability to configure resources, limits, and alarms.

4. Access equipment near to or far from the welding process.

5. Possesses predictable response times.

6. Communicates with different kinds of lower and higher level devices.

7. Provides remote (from the process or operator) functions.

8. Provides alarm handling and annunciation.

9. Provides fail-safe operation.

10. Tracks, collects, analyzes, stores, and displays welding data and process raw data into more meaningful information.

11. Supplies information, such as schedules or diagrams, to the operator.

12. Processes and provide textual and graphic current and past information about the welding process.

13. Allows the operator to request information and perform control actions through operator instructions.

14. Allows and prevents various operator actions.

15. Calculates welding performance.

16. Provides database service and facilities, both historical and real time.

17. Provides a platform for additional software applications

18. Provides communication and networking support.

19. Interfaces with different communication protocols.

The computer system has the following software features

1. Possesses a standard user interface.

2. Allows new software to be installed without requiring the operator to write programs. This is made possible by software designs that allow implementation and changes to be entered through a menu and executed without recompiling the programs.

3. Is easy to use by having editing facilities designed in the system which can be tailored to a specific process.

4. Produces textual output every time it is generated or modified. This output becomes part of the system documentation.

5. Provides on-line documentation through help screens and tutorials.

6. Uses text, graphs, and charts as necessary to provide high-level real-time graphic displays.

7. Provides hard copy reports of all major activities including maintenance logs, alarms and process history.

8. Compares continuously actual welding results against scheduled performance.

9. Supports many different kinds of input/output (I/O) devices through software I/O drivers and symbolic naming conventions.

10. Provides software security protection using different levels of user authorization, passwords and other types of security.

The computer system communicates the results of control and monitoring actions to operators and higher level machines.

Transfer of information with the operator will be bidirectional. The operator input interface supports keyboards, track balls, light pens, touch screens, or other input devices. The operator output interface supports video displays, hardcopy

devices, or other output devices.

An interface to a higher level device is required in most welding applications. Transfer of information with such a device will be bidirectional. The higher level device, although possibly smaller and less powerful than the computer system described this specification, provides direction and receives results. The computer system uses a network to implement the link to the higher level device.

The computer system provides for direct processing of input and output information from one or more machine and process input / output devices and subsystems.

The computer system has the capability to directly sense and affect the state of the welding and motion control devices without the use of intervening controllers. The connection to the machine or process inputs/outputs includes signal conditioning and related processing by the interfaces between the computer system and the process. These interfaces make no independent control decisions. It is the computer system which is responsible for making application-specific decisions based upon the inputs and outputs that are directly attached to the welding and motion control machines. This first level response results in enhanced welding control, and increased real time operation.

In some cases there is a connectivity option. Some machine or process I/O within the welding area, such as alarms, annunciators, alarm acknowledgment, and similar functions, can be performed as part of the operator interface and the inputs / outputs of the supporting devices can be connected to one or more device controllers. Alternatively, many of these devices can be attached directly to the computer system. Other devices, such as a vision system, or other detection and identification systems have an interface that is more appropriate to implement on the computer system, rather than on any of the device controllers. These devices can be attached to the computer system which passes the actual or transformed data (or some result of processing the data such as a schedule number) down to the appropriate device controllers for action.

Computer system hardware attributes

a. Networking

The computer system has network hardware that supports

1. Remote program load.

2. Remote diagnostics.

3. Remote testing.

4. Remote schedule downloading.

5. Remote and dynamic system changes.

6. Redirecting operational messages.

7. Remote console inputs.

b. Gateways

The computer system has gateway hardware to provide protocol conversion and resolve incompatibilities between other hardware and networks.

c. Console and operator interface

The computer system has an interface that provides teach mode, assist mode and authorization mechanism.

d. Operational modes

The computer system is able to execute in the following modes

1. Full function (production) mode.

2. Operator teach mode.

3. Debug or maintenance mode.

4. Device test mode.

5. Quality test mode.

e. Hardware design

The computer system operates reliably at high temperatures and humidity, and in environments with airborne particles, gaseous mixtures, mechanical shocks and vibrations, and ac power supply imperfections (e.g., voltage and frequency

fluctuations, EMI, RFI, and disruptions). Data integrity is critical, requiring **data protection** including parity and error correction codes.

Computer system software attributes
a. Application packages
The computer system contains the following application packages

1. Supervisory control.
2. Archiving.
3. Schedule management.
4. Document management.
5. Fault diagnostics.
6. Inspection/gauging.
7. Materials management.
8. Maintenance monitoring.
9. Parts/job tracking.
10. Process modeling.
11. Process simulation.
12. Program development.
13. Program library management.
14. Report generator.
15. Routing.
16. Scheduling.
17. Security and access authorization.
18. Tools management.
19. Tools monitoring.

b. Software design features
Once the hardware has been designed to be capable of certain throughput, the software design is a major factor that determines the overall performance. The computer system is required to have real-time or predictable response times. It is

able to handle data from high speed welding processes, and it is able to respond to operator inquiries in sufficient time to control the welding process.

Fail-safe operation

The computer systems is capable of fail-safe, fault-tolerant, operation. This may be accomplished by a system implementation that involves multiple processors configured in special ways and the use of special software. To the operator, such a system still appears as a single system.

III. CONTROLLER ARCHITECTURE

An appropriate controller architecture can consist of a VME backplane with several multitasking 68040 processor boards dedicated to the individual modules defined earlier. Welding and sensor control should each be allocated one processor board. A third processor board should provide the motion control and operator interface.

The main processor board coordinates the whole system. Coordination data is received by the sensor control processor board to define what databases are to be used and when the sensor control should be activated. In this way sensor processing can be altered in a pre-programmed fashion or in real-time in response to welding events or operator inputs.

The communications processor implements the sensor communications protocol and processes messages to ensure high speed communications between the controller and the various sensors.

Digital, analog, and system I/O boards connect to the backplane to provide the interface to the process equipment. These interfaces can be of different types and levels of complexity. In the low end of the range are simple serial I/O boards for low level sensors, alarms and similar devices. In the high end of the range are boards (for example, by Bit3 corporation) with dual ported memory connected to sophisticated devices, each a dedicated, self-contained, computer-based controller, such as sensor systems or robot controllers.

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Exchange of information between processors and I/O boards can be accomplished at a high level through distributed data structures in shared memory and dual ported memory that contain copies of all the parameter values that are relevant to the welding operations.

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15. Supplementary Notes

16. Abstract

     This report describes the requirements for an advanced automated weld system and the associated computer architecture, and defines the overall system specification from a broad perspective. According to the requirements of welding procedures as they relate to an integrated multiaxis motion control and sensor architecture, the computer system requirements are developed based on a proven multiple-processor architecture with an expandable, distributed-memory, single global bus architecture, containing individual processors which are assigned to specific tasks that support sensor or control processes. The specified architecture is sufficiently flexible to integrate previously developed equipment, be upgradable and allow on-site modifications.

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