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NEW PROTOTYPE AUTOMATIC AND INTELLIGENT SYSTEMS TO PLAN AND PERFORM SIMPLE SPOT WELDING TASKS.

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ABSTRACT
Work to create a new automatic spot welding system is described. With the co-operation of Ford Motor Company, experimental data regarding the parameters of spot welding processes were acquired and used to create a simple knowledge based system. By specifying parameters such as material thickness and type of material to be spot welded, the system was able to set the values of other parameters such as force, welding time and welding current. The knowledge base communicated with a spot welding controller and set the required parameters automatically. A DXF file processor was created to extract data from CAD drawings. The data from the CAD drawings were combined with data from the knowledge base and spot welding positions were calculated. These data regarding the co-ordinate positions of the spot welds were transferred to a robot controller and the movements were simulated.

Key Words – AUTOMATIC, INTELLIGENT, SPOT, WELDING, MACHINE.

I. INTRODUCTION

This paper describes work to create a new intelligent prototype system to automate the spot welding task. In this work the knowledge of experts were captured in a knowledge base that allowed the new system to calculate spot welding parameters and predict the theoretical spacing of the spot welds. This information was transferred to a welding head interface and DXF processor to allow automatic setting of the welding parameters and generation of a path for a robot. A number of interface programs were created in order to simulate the process. This work was an extension of work on design using distributed intelligence with advanced production machinery [1],[2] and on task oriented robotics [3][4]. Early results are described in [5] and [2].

The concept of a "task" had been given various definitions by different authors ranging from the production of a complete product, to a high form of structured programming [1]. Tewkesbury defined "task" as a specific production operation such as: spray painting, glue application, laser cutting and spot welding and, a task machine as a machine that is knowledgable in the area of one task. This concept of task and the concept of a task machine constrained to perform a task were adopted in the work described in this paper.

II AUTOMATION OF SPOT WELDING

Elihu Thomson invented spot welding in 1877. In the early 1880s it was used commercially and called incandescent welding [3]. Spot welding is a process in which two metals parts are fused together at localised points by passing a large current through the parts where the weld is to be made. The fusion is accomplished at relatively low voltage levels by using two electrodes to squeeze the parts together at the contact points and applying the current to the weld area.

The basic principle is that heat is generated when an electric current passes through an electrical resistance. The amount of heat generated depends on the amount of current, the amount of resistance and how long the current flows. These basic resistance spot welding principles are expressed by the following equation from [6]:

$$H = I^2RT.$$

Where: H = heat generated in joules, I^2 = current flow in ampere squared, R = resistance in ohms and T = time the current flow in seconds

The welding machines transform the supply to

low voltage high amperage welding power.
The control systems of resistance spot welding machines are all based around three functions [7]:

- Switching the welding current on and off at the required times.
- Controlling the amount of current.
- Activating the electrodes pressure mechanisms for various cycles and releasing them at the correct times.

Depending on the type of machine, the electrode force can be applied by hydraulic, pneumatic, magnetic or mechanical means.

Spot welding has traditionally been performed manually by either of these two methods. The first method uses a spot welding machine in which the parts are inserted between a pair of electrodes that are maintained in a fixed position. This method is normally used for small components that can be easily handled. The second method involves manipulating a portable spot welding gun into position relative to the parts. This has been used for larger components such as car bodies. The spot welding gun consists of a pair of electrodes and a frame to open and close the electrodes. In addition large electrical cables are used to deliver the current to the electrodes from the control panel. A spot welding gun with the cable attached is heavy and can exceed 45 kg in weight. This is shown in figure 1.

Fig. 1. A welding gun

To assist an operator manipulating the gun the apparatus is often suspended from an overhead hoist system. Even with this assistance the spot welding gun can be difficult to manipulate by the human operator at the high rate of repeatability and consistency required for car body assembly lines. As a result a robot has often been employed for this task.

In 1966 the first step was taken to use a robot to guide welding tongs. Its control unit was linked with external signals that commanded the robot when to squeeze, weld, hold, etc. By 1969 General Motors had installed a line of twenty-six Unimate robots for spot welding car bodies [8].

This was followed by Daimler Benz in 1970 in Europe who adopted a Unimate robot for a body side spot welding operation. From those beginnings the use of robots in this application has mushroomed and their importance has became so great that it has been necessary for the car manufacturers to consider the capabilities and limitations of the robots in designing the production line itself.

Fig. 2. Spot-welding process being performed by industrial robots.

The introduction of robots in automotive industries has continued so that more than 1200 were employed in 1980.

III. NDUSTRIAL ROBOTS

In this work a robot is defined as in [2], as a software-controllable mechanical device that uses sensors to guide one or more end effectors through programmed motions in a workspace in order to manipulate physical. Other definitions are included in [9] and [10].

As part of the work described in this paper a study of industrial robots was carried out with the co-operation of Ford Motor Company in Eastleigh, Southampton. Most of the industrial robots used were floor mounted and manufactured by either Kuka Roboter or ABB.

At the time of writing newer industrial robots called KUKA KR125 were replacing some of the older industrial robots. The new work described in this paper was based on these new robots. They were more efficient and met the definition quoted at the beginning of this section.

Some of its features were:

- Floor or ceiling mounted.
- Precision and repeatability of less than (+/-) 0.2 mm.
- A handling load 90-125 kg.
- High speed ranging from 100°/ second to 251°/second.
- Reach flexibility(maximum reach of 2.41 m for joint(1), 2.61m joint(2) and 2.81m joint(3).

The robot was controlled by a PC based controller KRC1 with a KCP Pendant programming unit using a Windows operating system. Further details on KR125, KRC1 and KCP can be found in [2].

IV. WORK COMPLETED

A number of interfaces were required for the new work:

- User interface.
- Robot controller interface.
- DXF file processor.
- Welding head interface.

These new interfaces were integrated with a new knowledge base to create a new automatic system for simple spot welding tasks. This is shown In [2].

Each interface was created and tested separately and then integrated using Object Oriented programming. Visual Basic 6.0 was chosen as a development tool because of this feature as well as compatibility with the Windows operating system, availability and access to technical support.

4.1 User interface.

The development of a new prototype user interface included the computer hardware (keyboard, mouse and screen), images on the screen (for example windows, menu, messages and help screen), command lines and user documentation such as manual and reference card. The user interface created during this work aimed to be user friendly and allow a low skilled user to interact with the new spot welding system with minimum training and supervision.

The concept of "usability" or being "user friendly" was considered along with the need for a mental picture of the end user, task definition and choice of development tool. The approach of using a knowledge base as a central controller was considered but found to be impractical because if the knowledge base was a separate control component then the system could be more flexible. The approach used was to allow the interfaces to interact with each other globally rather than having a centralised system. The sequence of events during the execution of the integrated system and the feasibility of extending the development of the interface to other industrial applications is being considered now.

4.2 Robot controller interface.

The joints and end effector movements of a Kuka KR125 were simulated in a robot controller interface described in [2]. The program was written using Visual Basic 6.0 for compatibility with the rest of the system. The inverse kinematics of a single and two-link system were considered. A number of assumptions were made to simplify the geometric description of a Kuka KR125 and a simple representation of this robot using inverse kinematics was created. The tasks that needed to be performed by the interface program and the program structure were considered. Methods for calculating the working envelope, joint angular position and time taken by the joints to reach the desired position were considered

Finally a graphical display of the robot was created and integrated to the rest of the system.

4.3 DXF file processor.

Data regarding the geometric description of an object was extracted and stored in appropriate form in Visual Basic 6.0. Each entity had a certain code representation in a DXF format and this was considered in the description of the general file structure, group code and how a DXF file could be interpreted.

Entities of concern in this work were “Line”, “Arc” and “Circle”. The program for the DXF file processor interface could be divided into four sections:

- Reading DXF entities.
- Extraction of their parameters.
- Detection of an overlap region.
- Calculation of spot-welds positions.

Flow charts showing the sequence of events during program execution and samples of codes for entity detection and storing parameters are included in [2]. A method of identifying a closed shape such as square or rectangle and how line objects were processed was used. A method was created to detect and define an overlapped region by collecting existing points on the drawing and calculating the points of intersections of the assembly components. Defining the overlapped area correctly was vital. Finally a method for calculating the spot weld positions was created. For simplicity only two-dimensional objects were considered in this early work but this can be extended to 3-D in future work. In order to illustrate this process further consider two simple work pieces as shown in figure 3.

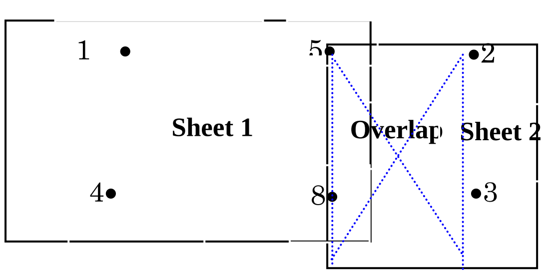

Fig. 3. Sample work pieces.

In this example Sheet 1 was made up of points 1, 2, 3 and 4 and the ownership for these points was 1. Sheet 2 was made up of points 5, 6, 7 and 8 and their ownership was 2. Following this a set of rules were created to compare the co-ordinate positions of all these points. The rules are described in pseudo code and consider point2 as an example:

If points ownership are not the same then
Compare the Y co-ordinate of the points
If they are identical then compare the X co-ordinate of the points
If X co-ordinate of point 2 is in between the X co-ordinate of point 5
and point 6 then store point 2 in “Zone” collection
End if

This example is simplistic since only the case with identical Y co-ordinate was discussed. The program was able to process other cases such as work piece comprised sloping lines. For detail information see [2].

4.4 Welding head interface.

A simple interface for the welding head controller was created in order to test the new knowledge base. All the calculated data was displayed on this interface and it generated advice regarding the type and size of the electrode diameter to be used for certain material thickness. The working principle of a conventional welding head controller and a method of verifying the heat setting of the welding transformer were considered.

4.5 Knowledge base.

With the co-operation of the Welding Integrity Team at Ford motor company in Southampton a set of experimental data regarding spot welding parameters were obtained. A knowledge base was created to:

- Determine the spot welding parameters.
- Calculate theoretical spacing between adjacent spot welds.
- Calculate theoretical spacing between the spot welds and the edge of work piece for a

given thickness and type of material.

This work is described in detail in Rasol[2]. The experimental data gathered was summarised in a tabulated form for both zinc coated and uncoated mild steel. Graphs of:

- Sheet thickness against weld current.
- Sheet thickness against weld time.
- Sheet thickness against tip force.

were produced. The relationships between these parameters were established from the results and a set of rules was created to generate algorithms for predicting spot weld parameters.

Data gathered (regarding the theoretical spacing of the spot welds) from "Rational welding" by Gray and Spence (1982), was used to generate algorithms for calculating the theoretical spacing of the spot welds. The knowledge base was capable of predicting the strength of an individual spot weld by employing the formulae:

$$\text{Weld strength} = 0.192 \times (\text{nugget diameter})^2$$

gathered from BS 1140.

Although the heat setting of the weld transformer was not dealt with, the feasibility of varying this quantity by varying the firing angle of the thyristors was considered.

The sequence of events that took place when the program was executed is shown in figure 4.

V. FUTURE WORK.

Neural networks are an interesting area that could be developed for future work. Other authors have proposed new methods of non-destructive testing using multi-layer neural networks where the variations of supply voltage and the electrode movement pattern were monitored using non-contact optical sensors for detecting electrode movement. Future work could consider two neural networks as pattern classification tools with outputs to determine the welding state and possibly reasons for failure.

Several authors have considered difficulties of measuring output parameters such as weld nugget using on-line methods. A method of predicting the nugget size using the input welding energy to assess the welding process could be considered instead.

It may be possible to fully automate the material selection and material thickness selection. The use of bar codes for the automatic selection and identification of components to be spot-welded could be incorporated. Dynamic resistance and heat transfer during the spot welding process could be modelled using numerical modelling techniques. From this the electrical and thermal response of the spot welding process and the influence on contacting force could be investigated.

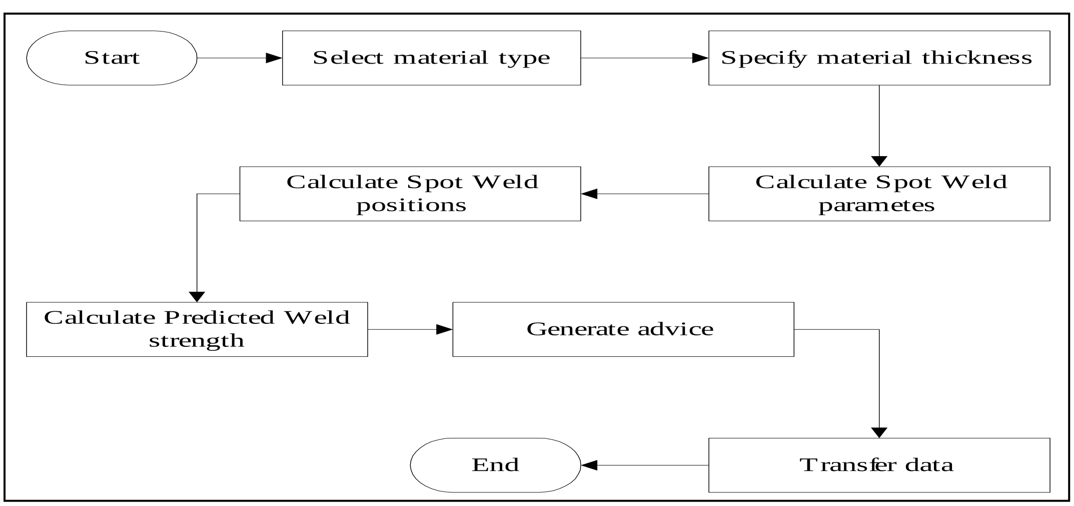

Fig. 4. The sequence of events.

The use of sensors in measuring temperature response using infra-red emission monitoring and cinematography have been considered.

The general use of artificial intelligence to create a new adaptive control system for the spot welding process could be considered and the use of a knowledge base system as a control component could be considered. The system could be made more general by considering the generic aspects of the knowledge-based system and those aspects that are special to the task.

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