Interfacing an optical profile sensor to an industrial robot for arc-welding

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INTERFACING AN OPTICAL PROFILE SENSOR TO AN INDUSTRIAL ROBOT FOR ARC WELDING

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ABSTRACT

Optical profile sensors for arc welding with robots are commercially available nowadays. Their promise to enlarge the application field of industrial robots in arc welding is restricted to the fact that the robot interface problem must be solved.

If the robot controller contains options for on-line path correction by external signals (adaptivity), one could derive control signals from these sensor data and distribute them to these external inputs in order to complete the total system. The described integration was set up to meet industrial manufacturing demands.

The robot, the welding equipment and the profile sensor should be unmodified industrial types.

1. INTRODUCTION

Vision systems in robotics is the innovation slogan of the last few years, delivering benefits in a higher production rate, based on the following terms:

- larger tolerances are permitted in the preparation of the workpieces;
- warpage during welding is detected, both robot and welding process will be adapted correspondingly;
- less accurate programming is needed, saving both operator and robot time;
- lower demands are made on the positioning of the workpieces with respect to the robot.

In spite of these prospects, reports of successful implementations and their application in manufacturing centres are scarce. The reasons for this can be summarized: The improvements need a high level investment. Moreover the interfacing is not straightforward, as will be reported.

The robot controller, even when it offers connections for external signal inputs together with robot instructions defining their influence on the robot behaviour, will generally not achieve that particular signal processing that matches the available sensor information.
This fact has many consequences. Either the robot instruction set has to be extended, possibly redesigned, or a separate computer has to be introduced, which is able to communicate with the sensor and to deliver control signals to the robot controller in a way which corresponds with the originally prescribed modes of operation.
In the latter situation the extra computer functions as the main process computer, acting as master of the welding system and thus containing the complete welding program. It has to contain interactive programs offering enough facilities for the operator to manage the welding process. Its digital outputs are connected to dedicated microprocessors, which provide the necessary signal acquisitions to meet the robot and welding equipment demands.

The intended result has been obtained: a convincing demonstration of the promising possibilities of robot welding if a profile sensor is added to observe seam variations during the welding and correcting actions are executed.

2. SYSTEM DESCRIPTION

In this paragraph the functioning of the components will be outlined.

2.1 The sensor

Numerous sensors are applicable in principle. Amongst these, contactless types are most attractive. Optical systems containing a laser light source and a solid state camera offer favourable results.
To avoid extremely high demands on system linearity and resolution, the sensor should not be stationary with respect to the workspace but connected to the weld torch, inspecting only the area of immediate interest.
The environmental conditions that occur in arc welding situations require dedicated sensor designs. Some demands are essentially contradictory, such as powerful optical arrangements to cope with the intensity of arc light interference, and small volume housings to deminish trajectory constraints of the robot. Water cooling and air streams to prevent dust intrusion are usual in these sensor techniques, complicating their design.

The sensor application attempts to achieve two goals: seam tracking and welding parameter control. By exploring the profile a few centimeters before the weld pool the information of the actual seamposition is available. Welding parameter adjustment relies on the calculated volume of the actual seam opening along the path. For the seam type concerned we use tables which contain the required wire speed and voltage as a function of the volume and welding speed. The table contents were compiled in dedicated experiments. They might be extended towards a large database, containing prescriptions for a wide application field.

In our experiments we used the Oldelft Seampilot (lit.1). Every .1s the seam profile is scanned by a laserbeam-linear CCD combination. Arranged for triangulation measurements, it delivers about 200 datapoints per scan. The scanning is obtained by a motor-driven oscillating mirror system (fig. 2). In this way all the laser energy is localized in one spot at a time, achieving a high signal to environmental light noise ratio and a high dynamic range. The data appearing at a high rate are processed in a nearby Camera Control Unit. Besides signal conditioning this CCU also provides laser power. At a greater distance, a Signal Processing Unit linearizes the data and calculates the rectangular presentation by trigonometric transformations. A pseudo third dimension is obtained by the forward movement of the welding torch.
For robot positioning we only need height and transverse deviation information from the expected values at proper times. To obtain this, the numerous profile data are entered in a template match algorithm. These calculations take some time: results are available .25s after the end of the scan.
The template type has been selected from a catalogue and characteristic data about it have to be previously defined. From this algorithm only the x,y coordinates of some vertices result, leading to a tremendous data reduction (fig. 3).

Only these vertices, the seam area and some other data for error detection are sent to the weld process computer in an IEEE 488 protocol.
In figure 1 the sensor connections are depicted, including the liquid and air connections.

The time available due to the travelling distance the torch has yet to cover to the respective point of measurement is amply sufficient for calculating robot setpoints and for selecting weld values from memorized weld parameter tables and then for adjusting the weld values. Both tracking and process control options will be dealt with in this way.

2.2 The welding equipment

The MIG-welding unit ESAB A32 is a thyristor-controlled rectifier, supplying power at a constant voltage which depends on an analog setpoint value. The wire speed is servo controlled by another analog voltage. Besides these, relais can be operated to switch power, shield gas and spatter cleaning to clean the torch after finishing the seam. The welding equipment is designed to be used in combination with the ASEA robot controller, thus providing the cable connections and safety circuits. The robot instruction set offers directives to manipulate these states. However, for reasons to be mentioned later, we used an extra process computer with the weld process in its memory. For this reason the arc welding software option in the robot operating system was not used. Instead of this, provisions were installed to control the welding unit by the process computer, using slave processors as interfaces. In this way we separated general welding progamming from signal acquisition programming, the latter being dependent on the types of the peripherals.

2.3 The robot

The applied robot ASEA IRb 6/2 incorporates "adaptivity" as an attractive option. Digital and analog input signals can be used to adjust a programmed path in accordance to sensor delivered values. The combination of this adaptivity and the TCP-programming mode offers the on-line sensor-guided arc welding.
In the early experiments, approaching the robot controller as a black-box with well-defined commands and operating behaviour, we noticed a certain retardation in the interpretation speed of the robot program statements, (and hence in their execution) when external signals are developed either from the joy-stick or from the signal input boards. Given this phenomenon, we decided on a strategy whereby, after a seamfinding procedure, the welding of a total seam takes place within only one robot program instruction. The somewhat tricky instruction

```
    POS V = 0%        (go to "next" position with velocity = 0)
```

illustrates this. In any case, the programmed velocity has to be chosen small enough so that the end-of-seam occurrence completes the execution of the instruction. In an alternative method we applied an external signal to obtain this robot arm progress.

In the leading part of the robot program a declaration has been given which reflects how to handle occurring external input signals. It contains input channel identification scaling factors and a direction vector for the desired velocity in an orthogonal vector system located at the TCP, which is the torch tip.

In our experiments, it appeared that the applied signals are read in at discrete times. The resulting velocity depends on the magnitude of the signal, expressed in the number of weighted bits. The velocity is not proportional to the input signal: within a considerable dead zone there is no response. By selecting a well-considered value for the scale factors this zone can be reduced to a minimum value. Expecting an immediate response to the applied signal, one should realise that the internal robot controller needs some processing time for the calculation of joint setpoints: a delay of about three sample periods is noticed at the beginning of the signal and a much shorter delay at the end of it. From the velocity we obtain the intended displacement, depending also on the signal duration which is converted to a number of samples.

2.4 The proces computer

Given the described behaviour and maintaining our goals to work with an unmodified robot, we decided to arrange an anticipating control by supplying carefully dosed control signals.
This takes place in dedicated microprocessors Intel 8039, called slave processors. During welding the sensor supplies profile data at a rate of 10/s. This is far too rapid for the cyclic control loop as can be seen from the symbolic programs:

```
procescomputer

initialise
repeat wait for 5th sensormsg
   calculate future setpoint
   store in buffer
   send actual setpoint to slave
   start-all-slaves
 until end-of-seam
```

```
slave i  (4 bit)

reset output
repeat wait for start-all-slaves
   read setpoint
   calculate bits and duty cycle
   wait ½ complement (duty cycle)
   set bits to output
   wait duty cycle
   reset output
until end-of-seam
```

During the initialising phase all the variables are defined and the seamfinding procedure is run in which the torch is moved towards the middle of the seam and towards a desired distance above it. At this point the shield gas relais is powered, as well as weld power ON, manipulator ON and wire speed ON.

From the entering previewed profile data we can calculate future setpoints for the torch. In order to delay their execution, the setpoints must be stored in a circular buffer. The buffer length expresses the delay time which is given by the relation of welding speed and parallax, i.e. the distance between measuring point and welding point. Corresponding to the fixed sensor message rate, the control loop will cycle every 500 ms. The division of the delay time by the loop cycle time, yields the buffer length.

The appearing sensor messages are read and interpreted. Future setpoints will be derived either from the average value of some previous message data or from the last one only. The V-groove is assumed to be symmetrical and, according to fig. 3, the y-coordinate of the adaptivity setpoint results from the averaged y1 and y4. The reference z-coordinate corresponds to the averaged z1 and z4. The message also contains seam volume data which enable us to adapt the welding parameters, using a table. Besides these, a "matched" boolean is presented, which plays an important role:
In those cases where no template match has been obtained within the specified tolerances, this variable is set to false. This may happen at the end of the groove, at tack welds or on rare occasions, e.g. when a metal drop disturbs the expected profile. These situations can be distinguished by counting the subsequent "not-matched" occurrences. In the latter case we calculate a setpoint value by extrapolation. However, if this not-matched sequence exceeds a limit, we conclude that the end-of-seam has been reached. Using this method, we can overcome tack welding, which disturb the profile only along a small distance.

At the end of the seam detection, the remaining contents of the buffer are sent to the slaves at the normal rate in order to finish the seam at the right spot. At this point a welding closure routine could be invoked, in which the welding parameters taper off, to prevent crater shaping. In our work we just switched off the weld power and the shield gas. Next a spatter removing action is executed in which the torch is cleaned by a strong air flow, and the robot moves the torch away from the workpiece.

2.5 The slave processor

The slave loops are synchronized to the process computer loops by the start-all-slaves commands.

An algorithm calculates the number of digital output lines to be set during a certain part of the looping time of 500 ms (duty cycle). The connected robot controller, receiving this input, will sample the signals at a rate of 50 ms. To prevent much accuracy loss, this duty cycle has to be chosen close to 100% and the number of bits adapted to this. The algorithm works the other way round: incoming values are classified along a discrete scale which corresponds to the number of bits, and next the value is divided by this number. The remaining number corresponds to the duty cycle.

If this output were to be applied to the robot controller we might obtain results as in fig. 4. From this figure it will be clear that deviations between the seam and the obtained trajectory will decrease if the output is delayed a while, e.g. distributed around the 50% time marks. This detail is arranged in the slave and symbolised by the instruction 'wait ½ complement (duty cycle)'.

3. EXPERIMENTS

A typical application in which seam tracking and welding adjustment is needed is the circumferential welding of steel pipe joints. The pipes are about 200 mm in diameter and have a wall thickness of 10 mm. The parts are pre-connected with tacks. The seams have been roughly prepared by grinding them by hand after cutting, resulting in a v-groove which is non-uniform along the circumference. The pipes are clamped in a manipulator which rotates them. Due to possible misalignment and the pipes being slightly oval, the position of the welding torch has to be corrected during the process. To this aim the sensor is connected close to the torch and both are connected to the robot wrist, according to figure 1. Apart from the welding appendages for cooling, shield gas and spatter cleaning, there is a water cooling circuit for the sensor and an air supply to reduce smoke disturbances.

Several welding prescriptions can be preset in the program or selected by the operator, e.g. the welding speed, the standard voltage and wire speed, the number of layers and several torch angles with regard to the objects. The welding process is preceeded by a seam find procedure in which the robot scans the scene until the sensor gets the profile in sight and commands the robot to position the torch above the seam at the proper height. At this point the parameters are set to proper values and all circuits are activated.

The functioning of the installation has been shown in several successful demonstrations. Encouraged by these successes and the interest from industry in the continuation of this project, the installation will be improved with regard to the following aspects:

1 - The process computer, a development system, will be replaced by a dedicated type;
2 - The synchronization in the slave-to-robot communication will be improved;

3 - A better connection of the sensor and torch to the wrist is considered.

Next to the described welding task the welding of more complex objects will be investigated.

4. CONCLUSIONS

It has been proved that on-line sensor controlled arc welding with standard robots can be performed if the adaptive control is exploited.

It appeared that the load at the wrist of the robot, which approaches but does not exceed the carrying capacity of the robot, influences the dynamic behaviour. Especially, weak joints contribute to back-lash symptoms. This is particularly harmful in cases where weaving patterns are needed for good welding results. Weaving patterns can easily be obtained by programming some alternating offset to the output values of the process computer. However, in this case the measured profile positions have to be corrected for the actual weave deviations, as the sensor takes part in the weave actions. This correction is hampered if unforeseen dynamic phenomena contaminate the expected robot or sensor positions.

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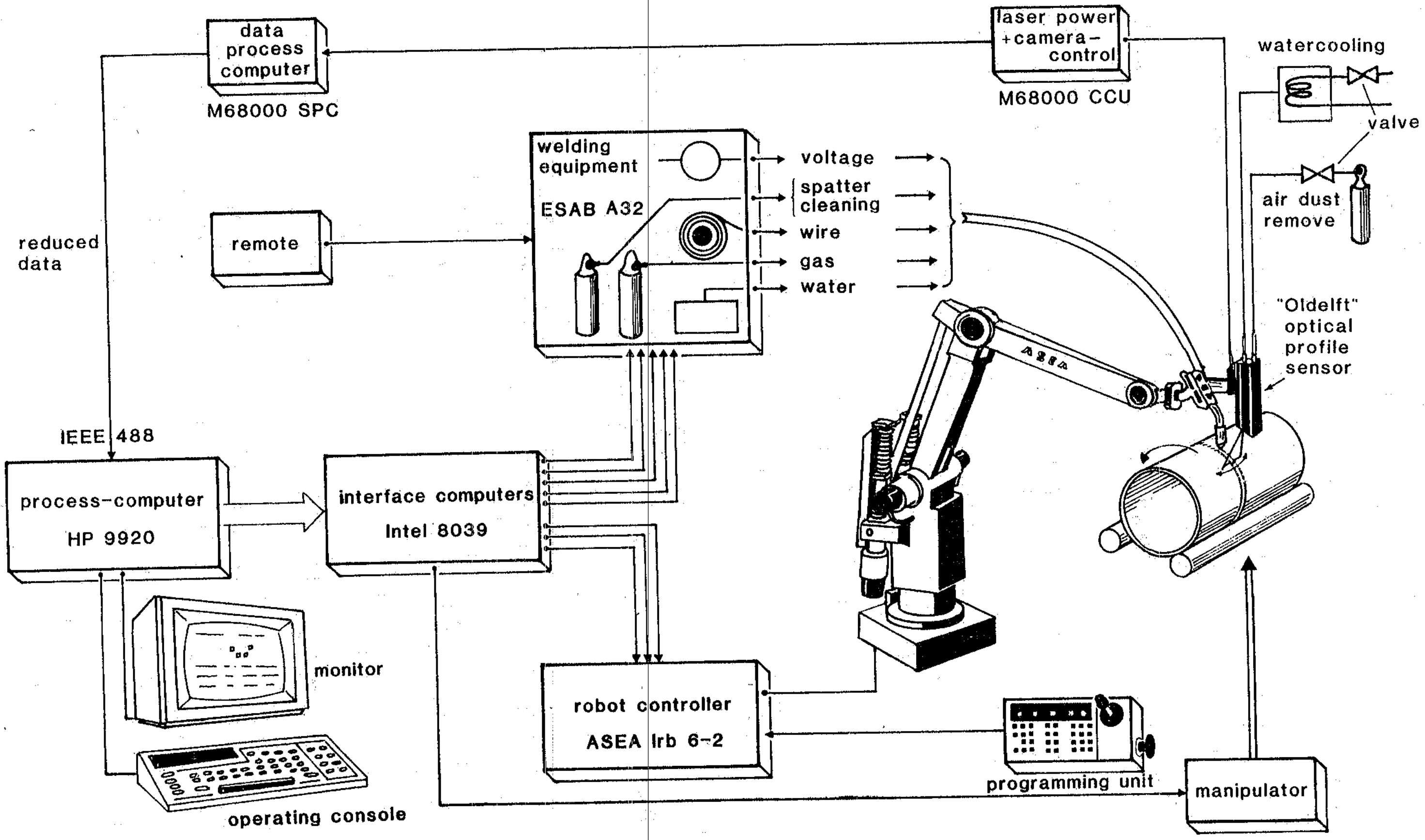

Figure 1. The integrated sensor-robot-arcwelding system.

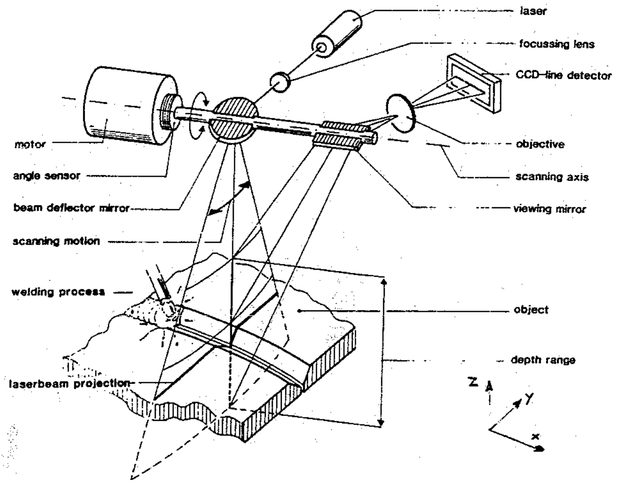

Figure 2. Sensor principle and detailed workpiece.

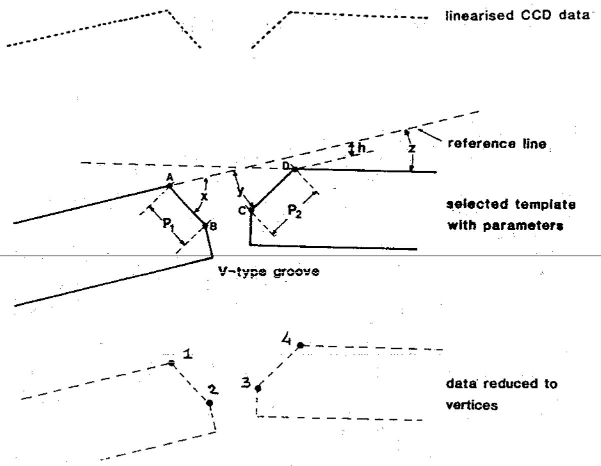

Figure 3. Template matching reduces data to four co-ordinate pairs in the YZ-plane.

Figure 4. Shifting the correction signal towards the middle of the 500 ms interval, yields a better approach of the rectilinear A-B trajectory.