특 별 강 연

MACHINE VISION SYSTEMS FOR INTELLIGENT WELDING AUTOMATION

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1. R & D GUIDELINES FOR ADAPTIVE WELDING

Adaptive welding includes the control during welding of the power source output, the weld metal feed rate, and the torch-to-workpiece relative position and orientation. It minimizes the harmful influence of the major sources of error encountered in open loop robotic welding, such as :

- o Deviation of the joint position from the programmed trajectory
- o Weld pool geometry variations
- o Mass balance deviations

In order to achieve robotic adaptive welding, coupling of active 3-D vision systems with intelligent software, advanced automation and welding data banks is required. Such integrated systems have the ability to cope with a great variety of situations currently occurring in industrial practice, and allow great improvements in productivity and product quality of most welded industrial components or equipment.

2. GENERAL UNDERLYING PRINCIPLES OF ADAPTIVE WELDING

Three major visual features of a welding operation form the core of the basic input necessary to implement adaptive welding and automatic quality control. Intelligent adaptive welding is designed over the dynamic detection of those features which are respectively the joint profile, the weld pool geometry, and the finished weld profile. In order to implement adaptive welding, those three features have to be detected, and their major geometric parameters accurately measured (See Fig. 1).

The joint profile position and orientation need to be determined accurately in order to generate the necessary corrective actions for process optimization and seam tracking. Seam tracking, coupled with rigourous welding parameter adjustments, requires the control of the torch orientation with respect to the seam direction. Features such as misalignment, gap and cross-section variations have to be measured in order to modify the welding parameters (welding current, welding speed, torch orientation, weaving parameters) and insure the optimum weld quality. The control strategy actually depends on the accurate measurement of these important observable variables.

The weld pool geometry and its relative position with respect to the gap are dominant inputs to insure sound welding conditions and weld quality. They are likely the main concerns of a human welder. Their adequate visualization offers the most severe challenge to vision systems because of the inherent optical noises emanating from the pool area. The weld pool geometry is of prime importance for the penetration control. This geometry is affected by preparation, fusion rate, and heat dissipation regime variations. Lack of adequate control of the pool geometry is a major sourrce of defects and often leads to rejects. True intelligent adaptive welding should include weld pool dimensional control.

According to most ineternational standards, rejects of welded components are essentially based on the geometry of the weld profile. Defects such as undercut, overthickness, etc., are examples of such defects usually defected through visual inspection. Automatic post weld inspection by 3-D vision systems closes the loop of intelligent adaptive welding. Accurate measurements of critical profile parameters can be done during post-weld inspection and defective areas sorted out in a reliable and relatively rapid operation, free from human errors.

At present, the first and third features are well under control. Further work is required to implement penetration control via weld pool dimensional characteristics measurements into the present adaptive welding system.

3. SELECTION OF A 3-D VISION PRINCIPLE

The adoption of a vision system implies the elimination of other types sensors. Vision has been privileged after a comparative analysis of the pros and cons of other sensors. The other types of sensors dedicated to seam tracking most commonly used in welding are based on dynamic mechanical contact, as in TACTILE SENSOR or electrical induction for inductive sensors, and on a contactless electrical measurement of the arc length THROUGH THE ARC SENSOR. Table 1 on the following page summarizes the conclusions of a comparison between these sensors and some vision-based sensors.

As can be seen, Table 1 easily privileges vision-based systems as the primary sensing device for adaptive welding. However, in order to measure in real time all the relevant parameters of a weld scene, vision systems that can operate in an area characterized by a very high level of optical noise are required, and the performances of the overall adaptive system are conditioned by the quality of the selected vision system.

Many techniques can be used to obtain 3-D images. Amongst those, the most useful technique for industrial inspection is the active optical triangulation because of :

- o Its flexibility and adaptibility to a variety of applications
- o Its range measuring zone suitability to adaptive welding
- o Its absolute coordinates measurement
- o Its robustness and suitability to industrial environments

Figure 3 illustrates various ways to achieve optical triangulation.

4. VISION SYSTEM CONTROLLER

Figure 2 shows a typical block diagram of the internal arrangement of a typical controller for a system based on optical triangulation with an autosynchronized scanning camera.

The camera control module keeps the temperature of the laser diode constant in order to insure a constant wavelerigth. It also controls the scanning mechanism and the laser power to cope with the variations of the surface condition. The range image generation module digitizes the analog signals coming from the CCD and the oscillating mirror angle. The resulting set of data constitutes the range image. It also calibrates the range image and yields spatial coordinates of each point using an appropriate software package.

The image analysis module, carries out several image processing tasks such as template matching and segmentation, and it handles tight-butt joints.

The application software module combines the data generated by the image analysis module and welding knowledge to command the process controller and host computer.

PHILOSOPHY BEHIND INTELLIGENT ADAPTIVE WELDING

Adaptive robotic control offers many advantages to the manufacturing industries. In order to be fully profitable, this technology, in addition to controlling the on-line operation, must integrate the early off-line steps of the process including process selection and optimization, and post welding operations such as weld quality control. Figure 4 shows the various links between software packages for on-line and off-line operations within a typical intelligent adaptive welding system.

5. EXAMPLES OF FIELD APPLICATIONS

There are few commercially available adaptive welding systems. Following are examples of field applications of Servo-Robot's integrated intelligent systems.

- o Robotic adaptive TIG welding of sheet metal cabinets
- o Sensor-based adaptive kit for laser beam welding of impact steel
- o Seam tracking butt welds of stainless and carbon steel pipes
- o Adaptive thick plate edge preparation (flame bevelling)

6. SUMMARY OF INTELLICENT WELDING ADAPTIVE SYSTEM

On-line operations are based on the visualization of the joint and the weld pool, coupled with a sound welding know-how stored in the pre-weld built-in data bank. The functions that should be performed by an adaptive system are :

- Computerized process optimization and model building
- Precision optical non-contact seam tracking of all weld joints
- Detection of arc start, end points and tacks
- Joint geometry measurements (gap width, misalignment, joint cross-section area, mass balance, pre-weld inspection)
- Adaptive control of welding speed, amperage, arc voltage, torch seam tracking position, wire stick-out, heat input, weaving motion
- Real time welding data logging system

- Statistical process control including logging of wleding trajectories and parameters, monitoring of machine performance, out-of-range control parameter display, upper and lower limit warning signals with color display
- Advanced robot interface for OEM users
- Rapid post-weld inspection
- PC color graphical user interface in Windows environment
- Weld pool vision with pool geometry and penetration control for high-quality processes such as TIG and laser welding

7. CONCLUSIONS AND CLOSING REMARKS

Although real technological progress has been achieved over the last few years, the large scale implementation of adaptive welding remains at the infancy stage. Further advancement is needed and it should be aimed particularly towards the reduction of the equipment cost and the promotion of its economic advantages.

In terms of research and development aimed at improving the performance, efforts must be made to further miniaturize the sensing devices. It should be noted, in this respect, the going from the SPOT to the M-SPOT camera has resulted in a weight reduction of over 50%.

The major challenge remains a reliable use of the weld pool visualization. Progress has been done in this particular area at the CEREM the material research laboratory of the French CEA, where a demonstration of the penetration control via optical pool width measurements could cope with sudden changes of the heat dissipation regime.(3) Earlier, Boillot and Begin had demonstrated, through a passive real time visualization of the weld pool irradiation, that penetration control could be achieved through weld pool width measurements when heat dissipation regimes were abruptly changed.(4)

However, there does not exist, to our knowledge, a commercially availabel system for weld penetration control via weld pool on-line observation suitable for all types of welds and all welding processes. Such a function would greatly improve adaptive systems for high-quality welding components.

Servo-Robot is dedicating a significant portion of its R & D activities to solve this problem through a modified BIP camera likely to become the TWIN family, a multifunction camera that will take into account the weld pool images.

Finally, adaptive system cannot progress without the active participation of the manufacturers of robots and welding machines, and that of the end-users. Cooperation between vision system designers, robot and welding equipment manufacturers and end-users, is a prerequisite for the expansion of intelligent welding adaplive system needed to cope with the challenges of worldwide competition and expanding market.

It is with this in mind that Servo-Robot has established cooperation with its customers and several research centers worldwide for the advancement of intelligent welding automation and to promote its dissemination in the industry.

TABLE 1

COMPARISON OF SENSORS' PERFORMANCES

Type	Principle	Functions	Comments
Tactile	Mechanical contact of wire or torch	Shift of original robot program	Not real time sensor Time-consuming Unreliable if real time
Inductive	Eddy currents	Seam tracking only	Possible parasite EM field interference
Arc	Differential measurements of arc parameters during torch oscillation	Seam tracking only	Low cost Limited processes
Structured	Triangulation with CCD array Spread laser beam illumination	Seam tracking, some joint metrology	Low S/N ratio No optimization of laser power
Laser scanning camera	Optical triangulation Flying spot illumination	Extensive metrology Seam tracking Adaptive welding	High S/N ratio Less sensitive to surface Less sensitive to surface conditions Programmable FOV Linear CCD Easier joint programming Adaptable to all types of joints and processes

References

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(2) M. Rioux, "Laser range finder based on synchronized scanners", Appl. Opt. 23, pp3837-3844, 1984.
(3) "Systeme SYLVARC" DTM / Services des Techniques avancees - Laboratoire Moderne de Soudage CEREM, CE Saclay.
(4) J.P. boillot, G. Begin. "Seam tracking and pool size control through analysis of IR emission", Welding 84, Brno, Czechoslovakia.

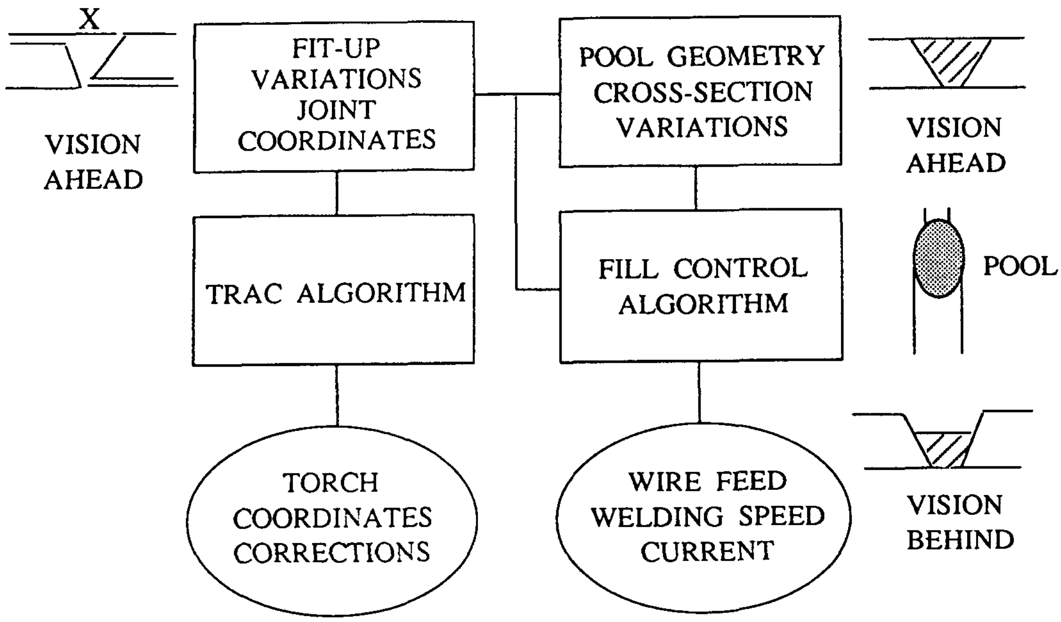


FIG. 1 : PRINCIPLES OF ADAPTIVE WELDING

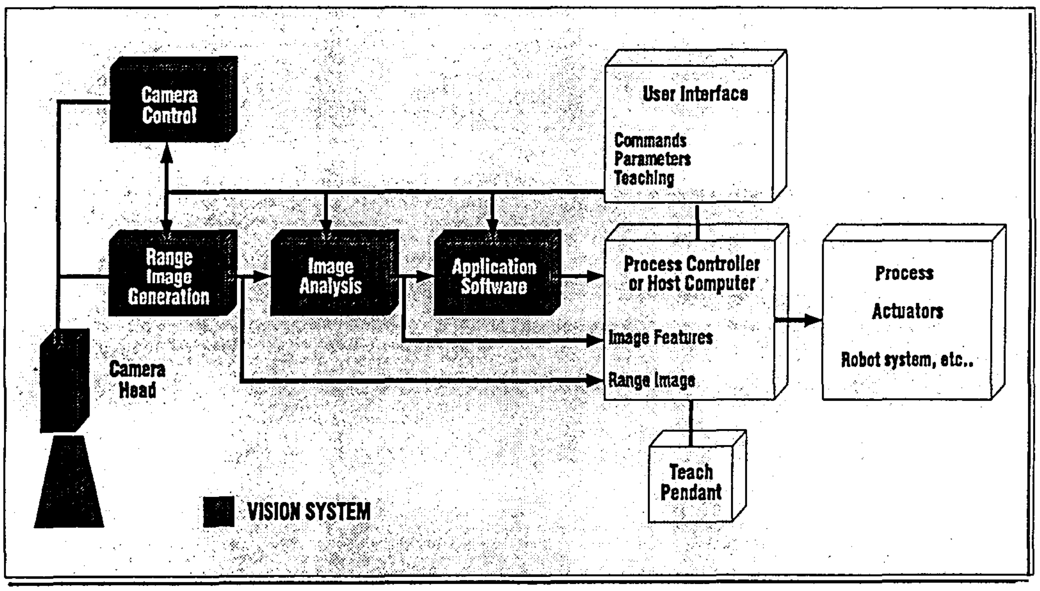


FIG. 2 : SCHEMATIC DIAGRAM OF OPERATION OF CONTROLLER

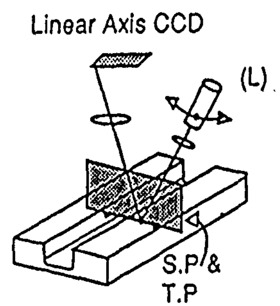
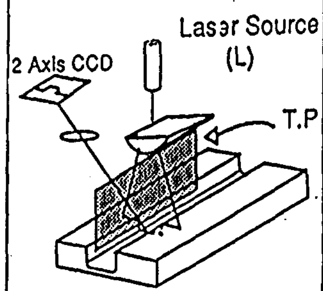
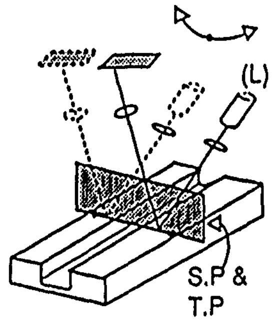
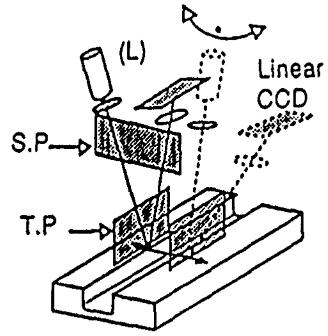
	Conventional scanning principle	Laser beam spreaded into a projected line	Autosynchronized scanning principles	
				
FEATURES	- Flying laser spot - Fixed receiving axis	- Laser line produced with cylindrical lens	- Flying laser spot - Detection and projection axes rotate together - Quasi Schelmpflug cond.	- Flying laser spot - Fixed triangulation geometry of projected axis and detection axis which rotate together - Schelmpflug condition
LASER SOURCE	- Optimized laser power to match surface property	-Optimized laser power for each profile	- Optimized laser power to match surface property	- Optimized laser power to match surface property
OPTICAL	- programmable (FOV) - small depth of field - less sensitive to amb. light - sensitive to shadow - relatively low resolution - low sens. to surf. cond.	-achivable high lateral resolution -fixed field of view (FOV) -fixed FOV/DOF ratio -minor sens. to amb. light -minor sens. to surf. cond.	- programmable (FOV) - large depth of field - not sens. to amb. light - minor sens. to shadow - better resolution - low sens. to surf. cond.	- programmable (FOV) - large depth of field - not sens. to amb. light - not sensitive to shadow - better resolution - low sensitivity to surf. cond.
DETECTOR	-Linear CCD: → easy data processing	- 2 axis CCD required: → complex data process.	- Compact - Linear CCD: → easy data processing	- Compact - Linear CCD: → easy data processing

FIG. 3 : IMAGING THROUGH LASER OPTICAL TRIANGULATION

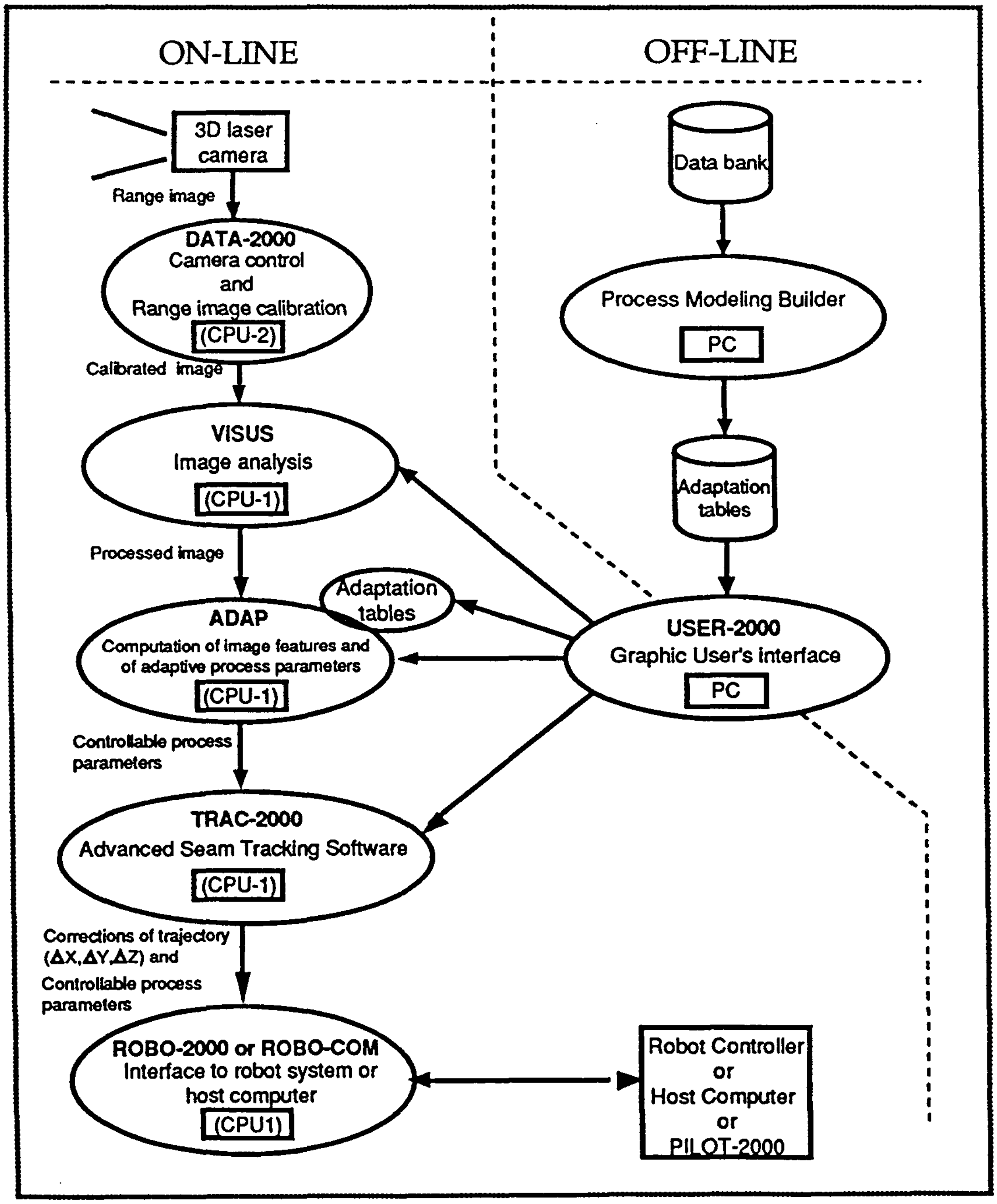


FIG. 4 : S-2000 PRINCIPLES OF OPERATION