Editorial

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Biographical notes: Yu Ming Zhang is a Professor and the Director of Graduate Studies in the Department of Electrical and Computer Engineering at the University of Kentucky, where he holds the James R. Boyd Professorship in Electrical Engineering and directs the Welding Research Laboratory and Applied Sensing and Control Laboratory. He received his PhD in Mechanical Engineering/Welding Major and MS and BS in Electrical Engineering/Control Major from the Harbin Institute of Technology, Harbin, China. He is a senior member of the IEEE and the SME and a member of the AWS and the ASME. He is the recipient of the Donald Julius Groen Prize from the Institution of Mechanical Engineers, UK, the A.F. Davis Silver Medal award and the Adams Memorial Membership Award from the American Welding Society and the 15th IFAC Triennial World Congress Poster Paper Prize and Application Paper Honorable Mention from the International Federation of Automatic Control.

George E. Cook is currently a Professor of Electrical Engineering and Associate Dean for Research and Graduate Studies, School of Engineering, Vanderbilt University. He received his BE from Vanderbilt University, MS from the University of Tennessee and PhD from Vanderbilt University in 1960, 1961 and 1965, respectively, all in Electrical Engineering.

1 Introduction

Welding usually involves the application or development of localised heat near the intended joint. Welding processes that use an electric arc are most widely used in industry. Other externally applied heat sources of importance include electron beams, lasers and exothermic reactions (oxyfuel gas and thermit). With these processes, fusion of the two parts being joined occurs as a result of the localised applied heat. The high energy density heat source is normally applied to the prepared edges or surfaces of the members to be joined and is moved along the path of the intended joint. The power and energy density of the heat source must be sufficient to accomplish local melting.

Resistance spot welding is another widely used joining process particularly in the automotive industry. With this process, the pieces to be joined are typically sandwiched between two electrodes through which a large electric current is allowed to flow for a controlled time duration during which pressure is applied. Heat is developed in the area of the spot from I^2R heating and the applied pressure serves to forge the two materials together. Another relatively new resistance welding process that relies on mechanically produced heat is the friction stir welding process. With this process, the welding tool is comprised of a shoulder in contact with the workpiece and a pin, which in butt welds extends almost completely through the workpiece thickness. As the tool rotates, frictional heat is produced at the contacting shoulder and pin surfaces causing the workpiece material to soften into the materials plastic state and flow around the tool pin from the front to rear, where it consolidates and forges under the confining pressure of the tool shoulder and regains strength upon cooling to form the weld. Unlike fusion welding processes, for example, arc welding, electron beam welding, laser welding, the friction stir welding process takes place in the solid phase below the melting point of the materials being joined.

Welding is a labour-intensive operation, which requires a variety of skills, training and experience. Research is needed on welding process sensing, modelling and control to develop automated welding machines, which can be as smart as human operators but can perform consistently in the harsh welding environment. Inputs to the welding process being controlled may include current, voltage, wire speed, travel speed, etc., which may be varied in real-time during the weld, and parameters such as electrode tip geometry, shielding gas type and wire diameter, which are usually held constant during the weld. Outputs of the process include geometrical features of the weld, microstructural characteristics and mechanical properties. Generally, these input and output parameters are coupled and non-linearly related.

A successful implementation of this coupled, non-linear weld process control problem involves

1 sensing

2 modelling and

3 control.

Issues dealing with each of these are discussed in the papers in this special issue.

In the first paper, 'Vision-based sensing of the welding process: a survey', G. Saeed presents a comprehensive review of the various ways that optical sensing has been used for sensing various aspects of the weld pool and welding arc plasma. Methods are reviewed for estimation of not only the surface dimensions of the weld pool but also the depth of the weld pool.

In the second paper, 'A compact vision sensor for weld pool surface sensing', Saeed, Zhang and Cook describe the hardware of a specific optical sensor based on projection and sensing of a structured laser light. Measuring only 45.72 mm × 32.512 mm × 54.102 mm, the compact sensor assembly is easily attached to the welding torch. The experimental results reported suggest that the weld pool penetration level can be inferred from the curvature of the laser line reflected from the weld pool surface.

In the paper, 'Modelling of friction stir welding for robotic implementation', Crawford, Cook, Strauss and Hartman present a 3D model of the friction stir welding process based on the computational fluid dynamics package, FLUENT. Two mechanical models, the Couette and Visco-Plastic fluid flow models, are simulated for Al-6061-T6. The simulation results are compared with experimental results at rotational speeds of 1500–5000 rpm and travel speeds from 4.66–26.7 mm/s. The results show that a decreased axial force versus increased rotational speed relationship exists, suggesting that this may be exploited for robotic friction stir welding where it is desirable to minimise the force requirements on the robot.

Continuing with the modelling aspect of welding control, Duan and Zhang describe a Cerebellar Model Articulated Controller- (CMAC-) based modelling method to estimate and control the topside and backside bead widths of the weld pool in high-power direct diode laser welding. The Gaussian function-based CMAC neural network acts as the inverse model of the controlled process after learning the experimental data under a variety of welding conditions. The CMAC model-based double-closed-loop system presented is shown to be capable of controlling the welding geometry of the non-linear laser welding process.

Four papers are presented that deal with current weld process control methods and the final paper looks at future theoretical concepts for adaptive control.

The paper by J.S. Thomsen deals with 'Control of pulsed gas metal arc welding'. This paper describes two aspects of the pulsed gas metal arc welding process that are of fundamental importance for successful manual welding. An arc length controller is described that is based on a non-linear model of the arc length process and uses feedback linearisation for cancellation of the non-linear terms. Secondly, a metal transfer controller is described that uses a melting model to determine when liquid drops at the tip of the electrode should be detached to ensure one drop per pulse and minimal energy for droplet detachment.

In the second controls paper, 'Vision-based neuro-fuzzy control of weld penetration in gas tungsten arc welding of thin-sheets' by Wu and Gao, a vision-based neuro-fuzzy system is developed to control the weld joint penetration in gas tungsten arc welding of thin sheets. A camera equipped with a specially designed light filter is employed to observe the weld pool from the topside of the workpiece. The weld width at the backside of the weld is estimated from a model describing its relationship to the weld pool surface geometrical parameters observed from the topside. The neuro-fuzzy controller takes into account the non-linearity, time-dependence and long time delay of the welding process.

The third controls paper, 'Adaptive voltage control of gas tungsten arc welding' by Crawford, Cook, Strauss and Hartman, also makes use of fuzzy logic control. It is shown that conventional PID control or fuzzy logic control is inadequate in controlling the arc length in gas tungsten arc welding over wide variations in the welding current. This is due to the non-linear relationship between changes in arc voltage versus change in arc length (arc sensitivity) over wide changes in welding current. As the arc sensitivity is part of the closed-loop transfer function of a conventional feedback controller, stability problems are typically encountered at weld start and stop when the current is varied from very low values to normal welding current, resulting in weld discontinuities particularly during the welding termination. To overcome this problem, an inverse fuzzy model is added to the conventional fuzzy controller to adaptively vary the conventional controller based on a desired model response and the actual system output. The adaptive system is shown to be capable of maintaining stable control over the full range of welding current, including the low values typically desired at start and termination.

The fourth controls paper, 'Predictive generic model control for non-linear interval systems with application in arc welding' by Istre and Zhang proposes a control technique for a class of non-linear systems with parameter intervals. This technique is a modification of the Generic Model Control (GMC), which specifies the desired derivative of the output as a proportional-integral function of the error between the reference and the output. In this paper, multi-step prediction is incorporated into the conventional GMC to develop a predictive algorithm suitable for the control of non-minimum phase systems. Both simulations and real-time arc welding control are demonstrated to be capable of using the interval predictive GMC algorithm for full effective control of the process. A novel welding process, termed pulsed keyhole plasma arc welding, is used for the experimental weld process control results.

The collection of controls papers concludes with a paper, ‘Robust adaptive control of uncertain non-linear systems with non-linear parameterisation’ by Yusheng Liu. On the basis of a robust Lyapunov control function and non-linear damping, this paper presents a robust adaptive control scheme for uncertain non-linear systems with non-linear parameterisation. With the proposed method, estimation of the unknown parameters of the system and generation of an additional signal are not required. There is only one adaptive parameter no matter how high the order of the system and how many unknown parameters may be present. Simulation results are presented to show that the proposed robust adaptive control scheme guarantees stability of the closed-loop system in the presence of unknown parameters, disturbances, non-linear uncertainties and unmodelled dynamics.

We believe that the nine papers presented in this special edition comprise a good representative ‘state-of-the art’ in weld process sensing, modelling and control. As the papers show, the field requires knowledge and application of a number of areas, including power electronics, signal processing, image processing, computer engineering, electromagnetics, control theory, materials science, fluid dynamics, thermodynamics, heat transfer, fracture mechanics, stress analysis, statics and dynamics, arc physics and others. It is a fruitful area for interesting research, and a lot of excellent contributions are being made.