Contents

1 Introduction ................................................... 1
   1.1 Development of Welding and Manufacturing Technology ....... 1
   1.2 Sensing Technology for Arc Welding Process .................... 3
   1.3 Visual Sensing Technology for Arc Welding Process ............. 3
       1.3.1 Active Visual Sensing .................................. 4
       1.3.2 Passive Direct Visual Sensing ............................ 6
       1.3.3 Image Processing Methods ............................... 9
   1.4 Modeling Methods for Arc Welding Process ..................... 13
       1.4.1 Analytical Model ....................................... 13
       1.4.2 Identification, Fuzzy Logic and Neural Network Models ... 14
       1.4.3 Rough Set Model ....................................... 18
   1.5 Intelligent Control Strategies for Arc Welding Process ......... 19
   1.6 The Organized Framework of the Book .......................... 23
References .................................................................. 23

   2.1 Description of the Real-Time Control Systems with Visual Sensing of Weld Pool for the Pulsed GTAW Process ............... 35
   2.2 The Visual Sensing System and Images of Weld Pool During Low Carbon Steel Pulsed GTAW ................................. 38
       2.2.1 Analysis of the Sensing Conditions for Low Carbon Steel 38
       2.2.2 Capturing Simultaneous Images of Weld Pool in a Frame from Two Directions ................................. 38
       2.2.3 Capturing Simultaneous Images of Weld Pool in a Frame from Three Directions ................................. 43
   2.3 The Visual Sensing System and Images of Weld Pool During Aluminium Alloy Pulsed GTAW ............................... 44
       2.3.1 Analysis of the Sensing Conditions for Aluminium Alloy 44
       2.3.2 Capturing Simultaneous Images of Weld Pool in a Frame from Two Directions ................................. 47
       2.3.3 Capturing Simultaneous Images of Weld Pool in a Frame from Three Directions ................................. 51
3 Information Acquisition of Arc Welding Process .......................... 57
  3.1 Acquiring Two Dimensional Characteristics from Weld Pool
  Image During Pulsed GTAW ........................................ 57
    3.1.1 Definition of Weld Pool Shape Parameters ...................... 58
    3.1.2 The Processing and Characteristic Computing of Low
    Carbon Steel Weld Pool Images .................................. 59
    3.1.3 The Processing and Characteristic Computing of
    Aluminium Alloy Weld Pool Image ............................... 69
  3.2 Acquiring Three Dimensional Characteristics from Monocular
  Image of Weld Pool During Pulsed GTAW .................................. 78
    3.2.1 Definition of Topside Weld Pool Height ................. 78
    3.2.2 Extracting Surface Height of the Weld Pool from Arc
    Reflection Position ............................................. 79
    3.2.3 Extracting Surface Height of the Weld Pool by Shape
    from Shading .................................................. 81
  3.3 The Software of Image Processing and Characteristic Extracting
  of Weld Pool During Pulsed GTAW .................................. 101
    3.3.1 The Framework and Function of the Software System ......... 101
    3.3.2 The Directions for Using the Software System ............. 102
  3.4 The Chapter Conclusion Remarks .................................. 110

4 Modeling Methods of Weld Pool Dynamics During Pulsed GTAW .......... 113
  4.1 Analysis on Welding Dynamics ..................................... 113
    4.1.1 Transient Responses with Pulse Duty Ratio Step Changes .... 115
    4.1.2 Transient Responses with Welding Velocity Step Changes .... 116
    4.1.3 Transient Responses with Peak Current Step Changes ....... 116
    4.1.4 Transient Responses with Wire Feeding Velocity
    Step Changes ...................................................... 117
  4.2 Identification Models of Weld Pool Dynamics ........................ 118
    4.2.1 Linear Stochastic Models of Aluminium Alloy Weld
    Pool Dynamics .................................................... 118
    4.2.2 Nonlinear Models of Low Carbon Steel Weld
    Pool Dynamics ..................................................... 123
  4.3 Artificial Neural Network Models of Weld Pool Dynamics ............ 126
    4.3.1 BWHDNNM Model for Predicting Backside Width
    and Topside Height During Butt Pulsed GTAW ..................... 127
    4.3.2 BNNM Model for Predicting Backside Width During Butt
    Pulsed GTAW ....................................................... 130
    4.3.3 BHDNNM Model for Predicting Backside Width
    and Topside Height During Butt Pulsed GTAW
    Based on Three-Dimensional Image Processing .................... 131
    4.3.4 SSNNM Model During Butt Pulsed GTAW ....................... 133
4.4 Knowledge Models of Weld Pool Dynamical Process ...............137
  4.4.1 Extraction of Fuzzy Rules Models of Weld Pool Dynamical Process ........................................137
  4.4.2 Knowledge Models Based-on Rough Sets for Weld Pool Dynamical Process Based on Classic Theory .................139
  4.4.3 A Variable Precision Rough Set Based Modeling Method for Pulsed GTAW .....................................150
4.5 The Chapter Conclusion Remarks ........................................161
References ..............................................................................161

5 Intelligent Control Strategies for Arc Welding Process ..............163
  5.1 Open-Loop Experiments ....................................................163
  5.2 PID Controller for Weld Pool Dynamics During Pulsed GTAW .....165
    5.2.1 PID Control Algorithm .............................................165
    5.2.2 Welding Experiments with PID Controller .......................166
  5.3 PSD Controller for Weld Pool Dynamics During Pulsed GTAW ...168
    5.3.1 PSD Controller Algorithms ........................................168
    5.3.2 Welding Experiments with PSD Controller .......................170
  5.4 NN Self-Learning Controller for Dynamical Weld Pool During Pulsed GTAW .................................................172
    5.4.1 FNNC Control Algorithm ............................................173
    5.4.2 Experiment of FNNC Control Scheme ............................178
  5.5 Model-Free Adaptive Controller for Arc Welding Dynamics ......182
    5.5.1 Preliminary of Model-Free Adaptive Control (MFC) ..........184
    5.5.2 The Improved Model-Free Adaptive Control with G Function Fuzzy Reasoning Regulation .......................186
    5.5.3 Realization and Simulation of Improved Control Algorithm 188
    5.5.4 Controlled Experiments on Pulsed GTAW Process .............190
  5.6 Composite Intelligent Controller for Weld Pool Dynamics During Pulsed GTAW .................................................194
    5.6.1 FNNC- Expert System Controller for Low Carbon Steel During Butt Welding ...................................195
    5.6.2 FNNC- Forward Feed Controller for Low Carbon Steel During Butt Welding with Gap Variations .................200
    5.6.3 Compensated Adaptive- Fuzzy Controller for Aluminium Alloy During Butt Welding ..........................205
    5.6.4 Adaptive-Fuzzy Controller Based on Nonlinear Model for Low Carbon Steel During Butt Welding with Wire Filler 210
5.7 The Chapter Conclusion Remarks ............................................218
References ..............................................................................220

6 Real-Time Control of Weld Pool Dynamics During Robotic GTAW . 221
  6.1 Real-Time Control of Low Carbon Steel Weld Pool Dynamics by PID Controller During Robotic Pulsed GTAW .........................221
6.1.1 Welding Robot Systems with Vision Sensing and Real-Time Control of Arc Weld Dynamics ............. 223
6.1.2 Weld Pool Image Processing During Robotic Pulsed GTAW 225
6.1.3 Modeling of Dynamic Welding Process .................. 231
6.1.4 Real-Time Control of Low Carbon Steel Welding Pool by PID Regulator During Robotic Pulsed GTAW .......... 234
6.2 Real-Time Control of Weld Pool Dynamics and Seam Forming by Neural Self-Learning Controller During Robotic Pulsed GTAW ..... 236
   6.2.1 Neuron Self-Learning PSD Controller for Low Carbon Steel Weld Pool .............................. 236
   6.2.2 Adaptive Neural PID Controller for Aluminium Alloy Welding Pool ................................. 239
6.3 Vision-Based Real-Time Control of Weld Seam Tracking and Weld Pool Dynamics During Aluminium Alloy Robotic Pulsed GTAW ................................. 244
   6.3.1 Welding Robotic System ........................................ 245
   6.3.2 Image Processing During the Robot Seam Tracking ..... 250
   6.3.3 Seam Tracking Controller of the Welding Robot .... 256
   6.3.4 Experiment Results of Seam Tracking and Monitoring During Robotic Welding ................. 258
6.4 Compound Intelligent Control of Weld Pool Dynamics with Visual Monitoring During Robotic Aluminium Alloy Pulsed GTAW .... 261
   6.4.1 The Robotic Welding Systems with Visual Monitoring During Pulsed GTAW ............................ 261
   6.4.2 Image Obtaining and Processing for Weld Pool During Robotic Welding .............................. 262
   6.4.3 Modeling and Control Scheme for Welding Robot System 265
   6.4.4 Penetration Control Procedure and Results by Robotic Welding .................................. 269
6.5 The Chapter Conclusion Remarks ................................ 271
References .................................................................. 271

7 Conclusion Remarks ............................................. 275

Index .................................................................... 277
Intelligentized Methodology for Arc Welding Dynamical Processes
Visual Information Acquiring, Knowledge Modeling and Intelligent Control
Chen, S.-B.; Wu, J.
2009, XXIV, 278 p. 502 illus., Hardcover
ISBN: 978-3-540-85641-2