Mechanical Systems and Signal Processing 60-61 (2015) 151–165

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Multisensor-based real-time quality monitoring by means of feature extraction, selection and modeling for Al alloy in arc welding

Zhifen Zhang [1], Huabin Chen, Yanling Xu *, Jiyong Zhong, Na Lv, Shanben Chen *

Institute of Welding Engineering, Material Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

ARTICLE INFO

Article history:
Received 18 March 2014
Received in revised form
11 November 2014
Accepted 27 December 2014
Available online 5 March 2015

Keywords:
Multisensory data fusion
Defect detection
Feature extraction
Feature selection
SVM-CV
Arc welding

ABSTRACT

Multisensory data fusion-based online welding quality monitoring has gained increasing attention in intelligent welding process. This paper mainly focuses on the automatic detection of typical welding defect for Al alloy in gas tungsten arc welding (GTAW) by means of analzing arc spectrum, sound and voltage signal. Based on the developed algorithms in time and frequency domain, 41 feature parameters were successively extracted from these signals to characterize the welding process and seam quality. Then, the proposed feature selection approach, i.e., hybrid fisher-based filter and wrapper was successfully utilized to evaluate the sensitivity of each feature and reduce the feature dimensions. Finally, the optimal feature subset with 19 features was selected to obtain the highest accuracy, i.e., 94.72% using established classification model. This study provides a guideline for feature extraction, selection and dynamic modeling based on heterogeneous multisensory data to achieve a reliable online defect detection system in arc welding.

1. Introduction

Sensor-based real-time monitoring of welding quality is the hot issue for the research of intelligent manufacturing process. Aluminum alloy pulsed gas tungsten arc welding (GTAW) is widely used in the aerospace, automotive and other industries. During the welding process, the welding seam quality can be easily disturbed by various factors, like the changes of electrode position and heat input, etc. [1]. Off-line traditional testing of welds, both destructive and non-destructive can be costly in terms of time, material, and productivity. Hence, several on-line welding quality monitoring solutions by means of the sensing technique have been proposed to provide real-time information to control the welding process and seam quality, such as vision sensor [2–5], arc sensor [6], acoustic emission sensor [7–9], temperature sensor [10] and spectrum sensor [11–14]. However, the single sensor applied in these reports can only obtain information reflecting the welding status from one point of view instead of the comprehensive information considering that the welding process is a highly nonlinear and time-varying complex process. Not to mention that the sensors may be easily disturbed by various and uncertain fluctuations, such as spatter, electromagnetism, noise, intense arc light and so on.

* Corresponding authors.
E-mail addresses: zzf919@sjtu.edu.cn (Z. Zhang), xuyanling991@sina.com (Y. Xu), sbchen@sjtu.edu.cn (S. Chen).
[1] Tel.: +86 21 34202740; fax: +86 21 34202740 808.

http://dx.doi.org/10.1016/j.ymssp.2014.12.021
0888-3270/

Multi-sensor information fusion technology, which can provide significant advantages over single sensor has the great potential of improving the satiability and robustness of the objective system and has been widely applied in different areas, such as robotics [15,16], intelligent transportation [17] and so on. Recently this technology has been tried and effectively applied in different welding process for different purpose, for instance, nugget size monitoring of resistance spot welding [18,19], welding penetration condition estimation in CO_2 laser welding [20,21] and joint quality monitoring in ultrasonic welding process [22]. As the number of sensors increases, less dimension of feature set and quick decision-made are highly demanded for real-time welding quality monitoring system, under this circumstance, feature reduction and optimal fusion method became more and more important to the whole system performance. For the time being, only a few general feature selection methods, like PCA [13], SFS [23] were mainly applied in plasma spectrum signal-based welding in-process quality monitoring to select more relevant information due to its high redundancy. Furthermore, researches about feature selection for multisensory data have been rarely reported in terms of welding quality monitoring in pulsed gas tungsten arc welding (GTAW).

In this paper, a novel methodology for real-time quality monitoring of aluminum alloy in pulsed GTAW is presented based on the fusion of spectrum, sound and voltage signals. In order to simulating the welding disturbance and defects, the repeatable and controllable condition, like porosity caused by hydrogen, different seam penetration, local caving and so on were artificially produced for plates butt welding experiment. The related experiment setup was carefully introduced in Section 2. Sections 3.1 and 3.2 will introduce the developed algorithm of feature extraction for the three signals respectively before the thorough analysis of the relationship between these feature parameters and the welding fluctuation and defects in Section 3.3. The feature-level-based data fusion frame was firmly constructed during the process of feature selection in Section 3.4, wherein the illustrating methodology, i.e., hybrid Fisher-based filter and wrapper was proposed and utilized to select the optimal feature subset based on which the constructed classification architecture, namely, SVM-CV, can obtain the highest estimation accuracy of welding quality. The method presented is generic in nature, hence applicable to a wide range of problems typically seen in welding quality monitoring and other manufacturing process condition monitoring.

2. Experimental setup

The experiments were performed on an automatic experimental system which is shown in Fig. 1. It consists of three parts: the welding system, the control and motion system and multisensory signal acquisition system. The welding system includes the TIG welding power with OTC INVERTER ELESON 500P-type, CM-271 type wire feeder, water cooling tank, welding torch and 99.99% pure Argon as the shielding gas. For the control and motion system, a host computer using VC++ multithreading application was utilized to control the welding parameter, such as wire feed speed, time and so on and drive work piece to move with multiple freedoms while the torch and the designed multisensory system remained quiescent.

The signal acquisition system is composed of three parts. Firstly, the spectral collecting system consists of a low-cost 3648-pixel spectrometer (Ocean Optics HR4000), which ranges from 185 to 1100 nm with the resolution of 0.2 nm, an optical fiber and an optical probe. The optical probe was fixed at a two dimensional positioning stage and approximately at 32 cm away from the electrode and has a deviation of 30° from the torch center after the careful calibration. During the dynamic welding process, the light of welding arc is transferred into the spectrometer through the optical fiber and the final data are transferred and stored in a PC for real-time processing through USB with the sampling period of 35 ms, which gives a detection accuracy of 0.1 mm for the welded seam.

The arc sound sensing system includes an omnidirectional capacitance microphone, i.e.,MP201, which has the frequency response from 20 Hz to 20 kHz and was fixed with the angle of 75° over the workpiece, and the MC104 signal conditioner to filter and amplify the signal. The voltage signal was collected by means of a hall sensor used to convert the welding current to voltage signal, and a protection circuit to isolate the high-frequency interference. Both sound and voltage signal were synchronously acquired with the sampling rate of 20 kHz by a data acquisition card in the computer. In addition, the real-

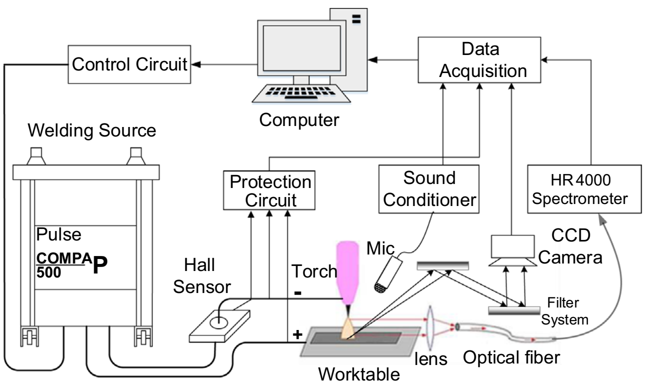

Fig. 1. Diagram of the experimental system.