Measurement 116 (2018) 114–121

Contents lists available at ScienceDirect

Measurement

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

Evaluation of welding skill using probability density distributions and neural network analysis

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ARTICLE INFO

Keywords:
High speed data acquisition
Sensors
Probability density distribution
Signal processing
Self-organized maps
Welding skill monitoring

ABSTRACT

Manual Metal Arc Welding (MMAW) is learned best by practice and the current procedure of assessing this learning is by inspection and/or testing of the weld. This is an indirect, expensive and time consuming method as the assessment can be made only after completion of weld and its subsequent inspection or testing. A possible alternative to this is the acquisition of electrical signals at a very high speed while welding is in progress and their subsequent analysis. Skill of the welder largely depends on ability of the welder in maintaining constant arc gap which, in turn results in steady state arc voltage. Hence, if voltage during welding can be acquired at a sufficiently high rate of acquisition, then this data can be analysed to assess welders' skill. Accordingly, data was acquired from trainee welders and from an experienced welder at a sampling rate of 100,000 samples/s and subsequently subjected to statistical and neural network analyses. Comparison of probability Density Distributions (PDDs) generated from these data and the neural network analysis revealed improvement in the learning of the welders with progress of training. These procedures were also employed independently to assess the skill of a large number of trainee welders at the end of their training. Ranking based on this procedure matched fairly well with that produced independently from visual examination of the weld.

1. Introduction

Manual Metal Arc Welding (MMAW) is the most widely employed welding process in the Indian fabrication industry. Quality of the welds produced by this process depends critically on the skill of the welder. Hence, training of the welders and evaluating their skill for welding are important requirements before employing welders for fabrication of critical components. At present, both monitoring of the learning and the evaluation of the skill of the welders are carried out by inspecting or testing of the welds produced by the welders for the quality of these welds. This is an indirect method because quality of the weld, not the skill of the welder is assessed based on the assumption only skilled welders can make good quality welds. This method is also time consuming and expensive as the welds can be inspected or tested only after completion of the welding and inspection and testing would require additional steps of specimen fabrication for testing and equipments for inspection and testing.

An alternative to this is to monitor variation in voltage and current and assess the skill of the welder based on the variation recorded in these two parameters while welding is in progress. Welding is a stochastic process in which there are dynamic variations in voltage and current while welding is in progress and for a given welding power source and consumable, these variations critically depend on the skill of the welder. However, these variations are so random and rapid that normal voltmeter or ammeter present in the power source cannot reveal them. A major cause of variation in voltage and current during welding is coming from the variation in the arc gap during welding, and ability of the welder to maintain a constant arc gap during welding depends critically on the skill. With the help of a high speed data acquisition system, welding voltage and current can be recorded at rates as high as 10^6 samples/s, which can clearly reveal the dynamic variations in voltage and current, while welding is in progress. Such a data acquisition was carried out for a group of trainee welders while they were welding. Subsequently, by analyzing this data it is shown that both monitoring the progress of learning by trainee welders and evaluation of the skill of the welders at the end of training can be carried out.

Analyses of the welding process using welding data acquired using high speed data acquisition system have already been reported in literature. For testing and optimizing the performance of arc welding processes different statistical methods like probability density

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https://doi.org/10.1016/j.measurement.2017.11.009
Received 11 April 2016; Received in revised form 25 October 2017; Accepted 2 November 2017

distribution (PDD) have been used by many [1,2]. PDD is the plot of the percentage of the total data for each of the discrete values of data recorded. Chen et al. has used PDD to show that the arc stability is improved with the use of nano powders of $CaCo_3$ in the flux coating [3].

Welding monitoring system based on field programmable gate array (FPGA) and measurements and processing of electrical signals from sensors placed on the welding transformer and electrodes has been proposed for detecting faults in real time and with high sensitivity [4]. In another study, welding data was acquired and current histogram plotted to explain the phenomenon of metal transfer in Gas Metal Arc Welding (GMAW) process by observing the current deviation from the histogram curve [5].

In Luksa et al. [6] a microprocessor based controller system for real-time collection and display of welding parameters was designed and developed and this system was used to detect welding imperfections in gas metal arc welding by recording the instantaneous values of welding parameters. In another study a range of parameters has been derived from welding data and the parameters thus obtained were used for fault discrimination. Here, authors have used independent component analysis to separate sampled data from the arcing and short circuiting stages of welding [7].

Development of welding process monitoring system based on a microcontroller platform capable of data acquisition, aggregation, and wireless transfer to a data server and presentation of this data in the form of a welding diary has also been reported [8]. This system could monitor and record all the relevant welding data and hence is capable of substituting the tedious manual filling of the welding data sheet. Recently acquisition of CO_2 welding signals using a data acquisition system and their subsequent analysis using VC + + and MATLAB mixed programming to obtain PDD and power spectral density (PSD) has also been reported [9]. Further, voltage and current signals acquisition has been used to study the alloy enrichment in the weld metal deposited using cellulosic electrode as function of welding parameters [10].

Praveen et al. [11] has studied arc voltage behavior in pulse gas metal arc welding (GMAW-P) under different drop transfer modes in which experimental measurements were made to investigate effect of drop transfer mode on change in voltage during GMAW-P process. It is shown that the welding arc is significantly affected by the molten droplet detachment and sudden change in voltage just before and after this event can be used to understand the characteristics of molten metal transfer in GMAW-P. Fault identification in GMAW-P by signature images [12] has been performed in which on the basis of signature analysis, classification of welding faults has been done. Subsequently by generalized fault recognition, it was possible to classify the unknown faults in a reasonable way and discriminate between similar types of faults [13].

Welding data acquired has also been processed using Artificial intelligence techniques to study various arc welding processes. Sukhomay pal et al. [14] has predicted the quality of pulsed metal inert gas welding by taking various process and statistical parameters of arc signals and provided these parameters as a input to neural network model to predict the weld qualities. Intelligent monitoring and recognition of short circuiting in Gas metal arc welding (GMAW) process by fuzzy kohonen clustering has been done by Wu et al. [15]. In another study fuzzy logic and neural network technique has been adapted for recognizing GMAW process disturbances [16,17]. Strength of weld joint has been predicted for pulsed metal inert gas welding by analysis of acquired welding current through wavelet packet transform analysis [18].

Recently, evaluation of welding power source and filler wires through signature analysis has been reported, where authors evaluated dynamic characteristic of the arc welding power source and used welding current PDDs to analyze and evaluate the instantaneous fluctuations that appears in flux cored wire arc welding [19]. Very recently, welding data acquired by a DSO has been used to study the SMAW process [20,21,22].

In the present study welding voltage and current data were acquired using a high speed DSO while welding is in progress. Subsequently, monitoring and evaluation of welder's performance has been done by analyzing the data thus acquired. This analysis was carried out using both statistical and AI techniques. Results of this analysis and practical implications of these results are presented in this paper. Before going to experimental details a brief description of Self-Organizing Map (SOM), the AI technique used in this study is given below.

1.1. Self-organizing map (SOM)

SOM is the one of the most popular neural network models that is used in AI techniques. While dealing with artificial neural network (ANN) model an important aspect that initially encounters is whether guidance is required for learning or not. In our application we required a technique in which little needs to be known about the characteristics of the input data, because we are dealing with data that have completely random behavior. ANN of the unsupervised learning type, such as the self-organizing map, has been used for clustering the input data and finding features characteristic to this data.

1.1.1. Network architecture

SOM network includes input of 'n' units which is actually the length of training vectors and 'm' output units as number of categories. Each input units are fully connected with outputs units as shown in Fig. 1.

SOM belongs to the category of competitive learning, but it is having an organization, which means having a lattice of output neurons that can be arranged in 1, 2 or even higher dimensional space (Fig. 2a). When we feed the input patterns (Fig. 2b), these patterns acts as stimuli to randomly distributed neurons to assign random weights and organize themselves based on the statistical distribution of the input data (Fig. 2c). Weight updation will take place for all iterations in such a way that the Euclidean distance between input vector and the weight vector is minimized. Consequently, one of the neurons will emerge as winner (black dot in Fig. 2). Due to the weight adjustment, winning neuron will move closer to input lattice and hence is indicative of statistics of input distribution. This property perfectly suits our application of grading the skill of welders, as good welder can maintain a stable arc gap, consequently data obtained will be such that more data will be accumulated near the steady arc voltage. Hence, position of winning neuron can easily reflect the skill of the welders.

2. Experimental setup

2.1. Welding

Fig. 3 shows the arc welding machine setup with data acquisition system. For monitoring the progress of learning, the instantaneous values of voltage and current data were acquired while bead-on-plate welding on carbon steel is being made by the trainee welders. Constant Current (CC) power source and E 7018 (3.15 mm dia) electrodes were used for this study. Current chosen for welding is 120 Amps and corresponding voltage displayed in the machine while making these bead-on-plate welds are 20 V, three sets of data were acquired from three

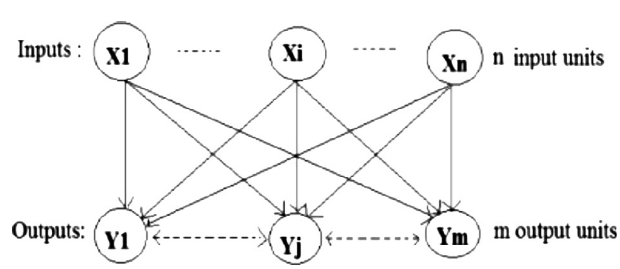

Fig. 1. Network architecture.