The real time analysis of acoustic weld emissions using neural networks

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THE REAL TIME ANALYSIS OF ACOUSTIC WELD EMISSIONS USING NEURAL NETWORKS


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Synopsis.

Artificial Neural Networks (ANNs) are becoming an increasingly viable computing tool in control scenarios where human expertise is so often required. The development of software emulations and dedicated VLSI devices is proving successful in real world applications where complex signal analysis, pattern recognition and discrimination are important factors.

An established observation is that a skilled welder is able to monitor a manual arc welding process by subconsciously changing the position of the electrode in response to an adverse change in audible process noise. Expert systems applied to the analysis of chaotic acoustic emissions have failed to establish any salient information due to the inabilities of conventional architectures in processing vast quantities of erratic data at real time speeds.

This paper describes the application of a hybrid ANN system, utilising a combination of multiple ANN architectures and conventional techniques, to establish system parameter acoustic signatures for subsequent on line control.

Introduction.

The Neural Applications Group at Brunel University, UK, has aimed its research at the development of autonomous products and control systems utilising state of the art technologies. One area of continuing study has been the development of a fully integrated, hybrid control system for automated welding processes; in particular industrial semi-automated submerged arc welding (SAW).

The successful application of Artificial Neural Networks (ANNs) to interpret ultrasonic echoes of the welding head in real time has yielded a system capable of seam tracking and monitoring weld penetration, highlighting the ANNs computational power when dealing with erratic, noise polluted data [1].

The relationship between the process variables of a weld and acoustic emission (AE), both audible and inaudible, has been the subject of various much research. It is an established observation that a skilled manual welder is able to intrinsically position the electrode and vary the arc length in response to adverse fluctuations of process noise.

Recent attempts to establish salient relationships between AEs and process parameters have utilised conventional digital signal processing techniques and expert systems to classify the data [2]. The inability of these systems to respond correctly to novel and erratic inputs was compounded by speed limitations in manipulating vast quantities of data in real time, causing data explosions and consequently negative results [3].
The aim of this research is the development of a hybrid system incorporating conventional DSP methods and ANN techniques to classify features within acoustic data relating to weld parameter fluctuations, in real time. It is envisaged that the acoustic method will complement the existing ultrasonic array in ultimately providing a single system able to monitor and control all the process variables.

The Weld Parameters

The creation of an optimum submerged arc weld is dependent upon six primary parameters:

- weld plate preparation (fit up)
- position of the electrode (seam tracking)
- rate of travel along the seam
- consistency of gravitational feed of the granular flux
- weld voltage
- weld current (determined by the rate of feed of the sacrificial electrode).

The nature of raw acoustic data is such that emissions could contain clues relating to all these parameters and eventual investigation will be given to achieving all possible acoustic signatures for diagnostic purposes. The primary objective, however, is the identification of signal patterns associated with changes in weld voltage. This method, when run in conjunction with the existing ultrasonic weld penetration monitor, would render a system capable of maintaining an optimum balance between voltage and current and hence achieve on line weld stability.

Data Acquisition

The transducer element consisted of three omni-directional electret condenser microphones (ECMs). The ECMs selected exhibited uniform frequency response characteristics suitable for infra, audible and ultrasound detection. The operation of ECMs negate the possible influence of induced noise created by the magnetic flux of the welding arc [4]. The transducer was mounted 300mm from the welding head together with suitably noise shielded pre-amplification.

The signals were then subjected to a series of eight active bandpass filters within the audible range, a low pass filter to isolate infrasound (break frequency 15Hz) and a high pass filter (break frequency 20kHz) to emphasise ultrasonic frequencies.

The data manipulation was achieved with the TMS 320C30 system board hosting Hypersignal Workstation software. The transient capture sampling frequency was set to 40kHz and 100ksamples enabling 2.5 sec of data capture at a 16 bit resolution. Samples were taken of ambient conditions as well as singular and combined readings of welding ancillary equipment such as the mains transformer, fume extractor fan and the kinetic control system. This provided sound intensity levels and features which could be identified within the final weld recordings.

Three welding runs were then initiated, with preset parameters and ten readings taken from each. The initial weld parameters were set at the default, the second run with low voltage and the final with high voltage in relation to weld current as shown in table 1.
The captured data was then subject to a 1024 point FFT analysis and a contour map obtained as shown in Figs 2, 3 & 4. Further manipulation enabled a power spectra analysis by performing an rms of the 715 FFT frames over the 2.5 sec capture period. This effectively removed transient noise pollution and yielded the most prevalent features in the frequency domain. Real time frequency and power spectrums were then monitored to gauge consistency over a complete weld run of 1 Metre lengths.

### Table 1.
Weld Voltage & Current Settings

<table>
<thead>
<tr>
<th>Weld Run</th>
<th>V</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (default)</td>
<td>41.1</td>
<td>820A</td>
</tr>
<tr>
<td>2</td>
<td>29.7</td>
<td>785A</td>
</tr>
<tr>
<td>3</td>
<td>61.2</td>
<td>815A</td>
</tr>
</tbody>
</table>

The Neural Classification Approach.

ANNs have been successfully implemented in scenarios where high speed signal processing of noisy or corrupted data has thwarted expert systems [2, 3, 5, 6]. The difference in the two systems stems from their architectures. The conventional computer relies on a single powerful processor passing synchronised data, whereas, neural systems contain many simple processors (neurons) heavily interconnected. This enables the parallel processing necessary to deal with complex signals at high speed. The advantages of networks lie in their ability to generalise and have consequently proven themselves in predictive systems requiring the assessment of novel data [7].

Observations of biological neural systems have shown that different neurons and topologies perform different functions. Similarly, differing ANN architectures and learning algorithms exhibit different characteristics of cognition and recognition. These characteristics can be exploited to great effect if the correct paradigm is selected for the situation. Pattern recognition problems are relieved by the extraction of salient features, by pre-processing, on which a pattern classifying network can base its considerations [8].

The well established ANN architecture of Back Error Propogation [9], often refered to as the 'work-horse' of neural computing, could be exploited in the area of signal processing. They have been successfully employed in bandpass functions and signal enhancement and could be used in pre-processing raw acoustic signals prior to DSP operation.

The basis of the signal pattern classifier for this research is the Kohonen Self-Organising Feature Map [10]. It is a two layered network of fully connected neurons that can self organise, from a random starting point, a topological map showing the natural relationships of the patterns used in its training data sets. This is achieved by the competitive activation of an output neuron dictated by the learning algorithm. The output neurons are arranged in a matrix so that each has theoretical neighbours. The activation threshold of neighbouring neurons are adjusted proportionally to the distance in vector space from the winning neuron. In this way each neuron is inhibited or encouraged to activate when presented with the next training set. The training continues
until a state of equilibrium occurs or an acceptable level of accuracy is reached. This system has proven successful in the interpretation of speech phonemes [11] and the diagnosis of lung infections via AEs [12]. In the same manner it is anticipated that this paradigm is capable of isolating similarities and grouping the signals common to unstable welds and separating them from stable inputs. Further sub-divisions within the topological map would include the remaining parameters which influence unstable welds.

Fig.1 illustrates the experimental set up. Research in this field of application continues.

![Experimental set up](image)

**Figure 1**
Experimental set up

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**Results**

So far research has concentrated on establishing usable characteristics in the frequency domain for introduction to a suitably tailored Kohonen classifier network.

Figures 2, 3 & 4 illustrate frequency contour mappings of the recorded data for weld runs 1, 2 & 3 (see table 1) respectively, from which the following observations were made:-

1. The vertical readings indicate noise from gas leakage through the flux. The concentration of this noise being most apparent on the low voltage run.
2. The high voltage and default runs show a consistent frequency feature in the 14kHz to 16kHz range.
3. The frequency intensities within this bandwidth are greater in the high voltage weld.
4. There is a substantial absence of low frequencies, up to 4kHz, on the default weld setting.

Figures 5, 6 & 7 illustrate the comparisons of real time freeze frame FFT analysis taken from a continuous weld run. The signals tend to enforce the observations made from the frequency contour map. The salient features are further enhanced with the real time power spectra analysis giving a 1024 point FFT 25 frame rms. An example for a high voltage setting is shown in Fig. 8.
SPECTROGRAPHIC ANALYSIS

Figure 2.
Frequency Contour Map, Default Weld.

Figure 3.
Frequency Contour Map, Low Voltage.

Figure 4.
Frequency Contour Map, High Voltage.
Figure 5.
Comparative Freeze Frame FFT, Low Voltage weld & Default Weld

Figure 6.
Comparative Freeze Frame FFT, High Voltage Weld & Default Weld

Figure 7.
Comparative Freeze Frame FFT, High Voltage & Low Voltage Welds
Conclusions

Conventional DSP methods utilising the TMS320C30 are capable of providing real time signals, in the frequency domain, which yield distinguishable features associated with non-optimum weld voltage settings for SAW.

It is feasible that a Kohonen Feature Map could be generated to indicate stable and unstable weld states from successive on-line power spectra.

Complex signal processing and classification of noise corrupted data often require the combination of conventional digital and neural techniques.

The research and development of weld automation continues, with the application of ANN technology, toward the provision of a fully integrated welding system.

References


