基于PCA_Nu-SVR的水下焊缝偏差识别方法

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摘　要：为了实现基于旋转电弧传感器的水下自动焊接，并获得良好的跟踪精度，必须研究水下的焊缝偏差识别算法．首先对采集到的焊接电流信号进行小波滤波和中值滤波，然后进行周期化和数据归一化处理．将主成分分析(PCA)线性降维方法与支持向量回归机(Nu-SVR)回归算法相结合，利用PCA对输入的样本数据进行主成分分析，消除输入波形数据间的自相关性，并作为支持向量回归机的输入．结果表明，基于PCA_Nu-SVR的焊缝偏差识别算法比区间积分法和神经网络法具有更好的识别效果，精度与支持向量机法相差不大；在运算速度上，比区间积分法慢，但比神经网络法和支持向量机法高．

关键词：旋转电弧传感器；水下焊接；主成分分析；支持向量回归；焊缝偏差识别
中图分类号：TG441.7　**文献标识码**：A　**文章编号**：0253-360X(2011)03-0021-04

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0 序　言

随着人类向海洋进军，水下焊接作为水下工程结构安装和维修施工中不可缺少的重要工艺手段，越来越受到各海洋大国的重视[1,2]．水下焊接的自动化是水下焊接技术的一个重要发展方向．

基于旋转电弧传感器的焊缝跟踪系统直接使用焊接电流信号作为传感信息进行焊缝跟踪．其检测点即为焊接点，结构简单可靠，成本低，故它成为目前最常用焊缝跟踪方法之一，近年备受人们关注．

基于旋转电弧传感器的水下焊接电流信号比陆上焊接受到更多的干扰，所得的焊接电流信号稳定性更差，这就要求水下焊缝偏差识别算法具有良好的抗干扰能力．目前基于旋转电弧传感器的常用陆上焊缝偏差识别方法有区间积分法、神经网络法、支持向量机(SVR)，但区间积分法容易受噪声干扰，神经网络法由于采用经验风险最小化的原则，在样本有限时，学习过程容易陷入过学习、维数灾难、局部最小等问题．支持向量机是建立在结构风险最小化的统计理论基础上，有效地解决了机器学习中遇到的各种问题．当输入向量较大时，将严重影响算法的运行速度．由于电流波形信号之间存在着一定的相似性，因此，提出一种结合主成分分析(PCA)和Nu-SVR的算法来实现水下焊缝偏差识别．

1 信号滤波

旋转电弧传感器获得的水下焊接电流信号不仅包含有焊缝坡口信息，同时受到许多噪声、短路过渡、息弧等干扰影响[3]．对旋转电弧传感器电流信号进行滤波就是从受到干扰的信号中提取由于焊枪扫描坡口导致弧长变化而引起的焊接电流的变化信息．图1为采集到的一组比较典型的水下焊接电流波形，其试验条件为旋转半径3 mm，旋转频率20

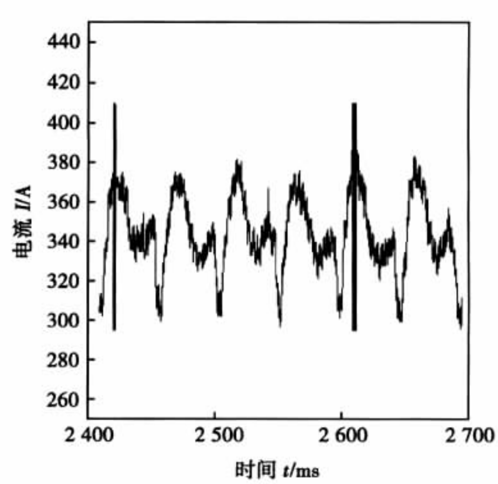

图1　采集到的电流信号
Fig. 1　Acquired welding signals

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Hz,焊接速度为 10 mm/s,电弧电压 38.5 V,电弧旋转方向为逆时针. 与陆上电流信号相比,水下焊接电流信号受到的干扰更多,需要针对其干扰信号特点进行滤波.

1.1 小波滤波

由于小波滤波具有很好的时、频局部化特性,能有效滤去非平稳信号中的噪声,所以采用小波滤波的方法进行滤波处理. 小波滤波方法主要取决于阈值、阈值函数、小波基函数和分解层数等参数. 经研究,文中选取阈值为 $\delta\sqrt{(2\ln M)}$,其中 M 为信号长度,δ 为噪声的标准偏差,其利用第一层的小波系数估计;采用软阈值函数,小波基函数为 coif5,分解层数为 5 层. 小波滤波后结果如图 2 所示.

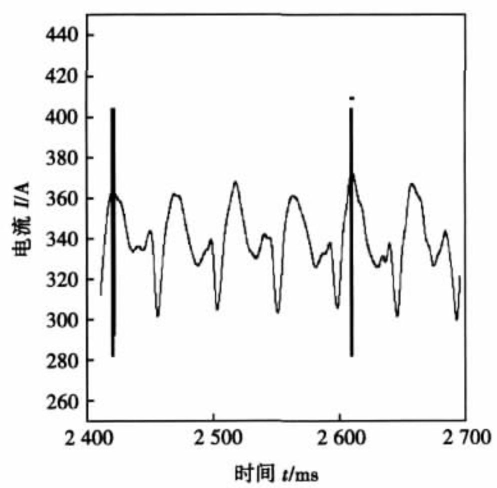

图 2 小波滤波后电流信号

Fig. 2 Signals after processed by wavelet filtered

1.2 中值滤波

由于小波滤波后信号中还存在短时间内信号振荡和息弧的干扰,需要采用中值滤波进行非线性滤波. 经过小波滤波和中值滤波后的信号如图 3 所示. 对滤波处理后的电流周期信号进行周期划分和归一化处理,构建成样本数据集. 图 4 为周期划分和归一化后不同偏差的电流波形.

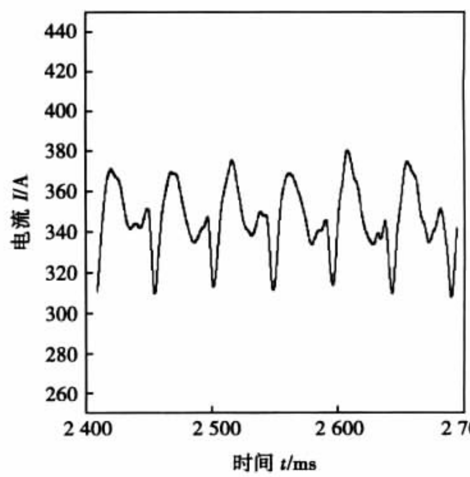

图 3 小波滤波和中值滤波后电流信号

Fig. 3 Current signals processed by wavelet and median filtered

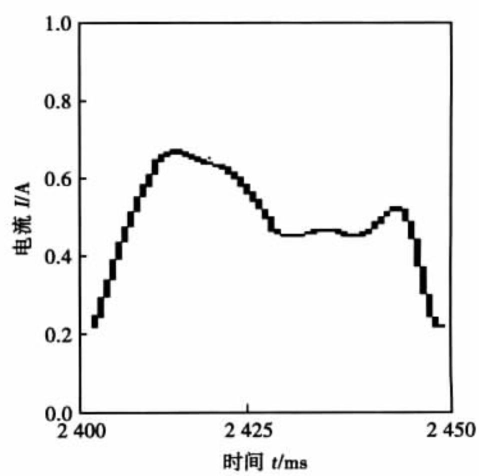

图 4 周期划分和归一后的电流信号

Fig. 4 Signals after processed by periodized and normalized

2 PCA_Nu-SVR 方法

根据旋转电弧传感器检测偏差的原理,不同的偏差值对应着不同的电流信号. 通过计算采样频率和旋转频率的商,可知每个周期的电流信号为一个 500 维的向量. 当 500 维的向量作为 Nu-SVR 的输入时,将严重影响 Nu-SVR 的训练速度和识别速度,不适用于实时性要求高的水下焊缝跟踪系统. 由于电流信号间具有一定的相关性,可以通过数据降维压缩数据和去除高维空间中数据不稳定带来的干扰,从而加快 Nu-SVR 的运行速度和提高其识别的鲁棒性.

主成分分析(PCA)是一种常用的统计分析方法,通过计算高维数据主成分,将其投影到较低维空间. 其优点是运算简便,并能产生简单的变换函数,能有效消除数据间的共线性,所以采用 PCA 进行数据降维.

2.1 主成分分析

PCA 是通过对原始变量的相关矩阵或协方差矩阵内部结构的研究,将多个变量转换为少数几个综合变量即主成分,从而达到降维目的的一种线性降维方法. 这些主成分能够反映原始变量的绝大部分信息[4]. 对于 n 维向量的样本集 Γ_i($i=1,2,\cdots$

n),定义其样本协方差矩阵为

$$C=\frac{1}{n}(\Gamma_i-\psi)(\Gamma_i-\psi)^{\mathrm{T}} \tag{1}$$

式中:ψ 为 Γ_i 的均值. 对协方差矩阵进行正交分解,即

$$(\lambda_1,\lambda_2,\cdots\lambda_n)=D(\boldsymbol{C}) \tag{2}$$

式中:D 表示求解矩阵的特征值,选取前 k 个协方差矩阵 $\boldsymbol{C}$ 按降序排列的特征值($k\leqslant n$),然后利用特征值和特征向量重构矩阵,这样实现降维.

2.2 向量回归机(Nu-SVR)

回归分析可以归结为寻求最优回归超平面问题,等同于凸约束条件下的凸二次规划问题[5,6]. 在 Nu-SVR 中该问题描述为

$$\left.\begin{aligned}&\min_{w,b,\varepsilon}\left\{\frac{1}{2}\|w\|_{\mathrm{H}}^2+C\left[\upsilon\varepsilon+\frac{1}{n}\sum_{i=1+}^{n}\varepsilon_i(+\varepsilon_i^*)\right]\right\}\\&\text{约束}\ [(w\cdot x_i)+b]-y_i\leqslant\varepsilon+\varepsilon_i^*\\&y_i-[(w\cdot x_i)+b]-\leqslant\varepsilon+\varepsilon_i^*\\&\varepsilon_i\geqslant 0,\ \varepsilon\geqslant 0\end{aligned}\right\} \tag{3}$$

式中:(x_i,y_i) 为样本数据;w 为线性函数的系数;常数 C 为惩罚函数;$\varepsilon_i,\varepsilon_i^*$ 为松弛因子,分别对应于最优回归超平面上方和下方的样本点.

把 $w=\sum_{i=1}^{N}(\alpha_i^*-a_i)\phi(x_i)$ 代入式(3),原始问题的对偶问题为

$$\left.\begin{aligned}&\min_{\alpha,\alpha^*}\frac{1}{2}\sum_{i,j=1}^{l}(\alpha_i^*-\alpha_i)(\alpha_j^*-\alpha_j)\cdot\\&<\phi(x_i),\phi(x_j)>-\sum_{i=1}^{l}y_i(\alpha_i^*-\alpha_i)\\&\sum_{i=1}^{l}(\alpha_i-a_i^*)=0\\&\alpha_i,\alpha_i^*\in[0,\frac{C}{l}],i=1,\cdots l\\&\sum_{i=1}^{l}(\alpha_i-a_i^*)=C\cdot\upsilon\end{aligned}\right\} \tag{4}$$

式中:$\phi(.)$ 为核函数;υ 用来控制支持向量个数或错误样本点个数;$<.,.>$ 为卷积操作,其决策函数为

$$\sum_{\text{支持向量}}(\alpha_i-\alpha_i^*)<\phi(x_i),\phi(x)>+b \tag{5}$$

由于引入了核函数 $\phi(.)$,能实现非线性的数据拟合. 支持向量机建立回归模型优先解决的问题是核函数的选择. 对于较小的特征空间,在没有先验知识指导的情况下,用径向基核函数往往能够得到较好的拟合结果,因此选取应用最广泛的高斯径向核函数作为试验的核函数.

2.3 PCA_Nu-SVR 方法

采用 PCA 与 Nu-SVR 结合的算法进行焊缝偏差识别,就是利用主成分分析对波形信号进行降维处理,把原始样本数据空间作为一个整体进行数据降维,作为 Nu-SVR 的输入,通过消除输入数据间的相关性,实现数据压缩,提高 Nu-SVR 的鲁棒性和运行速度.

下面列出 PCA_Nu-SVR 的焊缝偏差识别算法训练阶段的步骤为①采集样本数据,构建样本集;②进行小波滤波和中值滤波;③划分周期和归一化处理;④对数据进行主成分分析;⑤对数据进行交叉验证;⑥通过交叉验证获得最佳参数;⑦选择最佳参数进行训练. 识别阶段步骤为①采集样本数据;②进行小波滤波和中值滤波;③划分周期和归一化处理;④把数据投影到特征空间;⑤输入到 Nu-SVR 进行识别,输出偏差.

3 基于 PCA_Nu-SVR 的偏差识别结果与分析

主成分分析的主要目的是消除电流波形间的线性关系,降维后的维数是通过前 k 个主元的方差贡献率来确定,贡献率公式为

$$\theta=\sum_{i=1}^{k}\lambda_i/\sum_{i=1}^{n}\lambda_i \tag{6}$$

式中:λ_i 为矩阵 $\boldsymbol{C}$ 按照降序排列特征值. 本样本数据集的主成分分析结果如表 1 所示.

表 1　主成分分析结果

Table 1　Results of PCA method

特征值序号	特征值 λ_i	贡献率 θ(%)	累计贡献率(%)
1	500.737	94.87	94.87
2	12.920 5	2.45	97.32
3	7.634 1	1.44	98.76
4	2.562 8	0.49	99.25
5	2.391	0.45	99.70
6	0.728 1	0.14	99.84
7	0.370 0	0.07	99.91
8	0.221 9	0.04	99.95

如表 1 所示,前 8 个主成分的累计贡献率已经高达 99.95%,远远高于通常要求的 85%,所以其后的主成分可以忽略不计. 利用主成分 1 至 8 重新构建焊缝偏差识别的样本集,降维后向量与偏差数值作为 Nu-SVR 的训练输入. 进行焊缝偏差识别时,通过矩阵变换把待识别数据投影到降维后空间,再通过 Nu-SVR 进行识别.

焊枪左偏于焊缝和焊枪右偏于焊缝的电流信号存在水平翻转的关系,所以只进行焊接路径由偏差

为 0 到右偏 2 mm 的间变试验来验证算法的识别结果. 图 5 为各种方法的识别结果,表 2 为识别算法计算 10 个周期偏差的平均运行时间、最大误差和平均误差. 结果表明,PCA_Nu-SVR 算法精度与普通的比支持向量机法相差不大,比区间积分法和神经网络法更高. 在运行速度上,比区间积分法慢,比神经网络法和支持向量机更快. PCA_Nu-SVR 能很好解决水下焊接电流信号的不稳定的问题,获得良好的识别效果. 同时 PCA 算法能有效降低样本空间的维数并消除输入间的自相关性,提高 Nu-SVR 的运行速度.

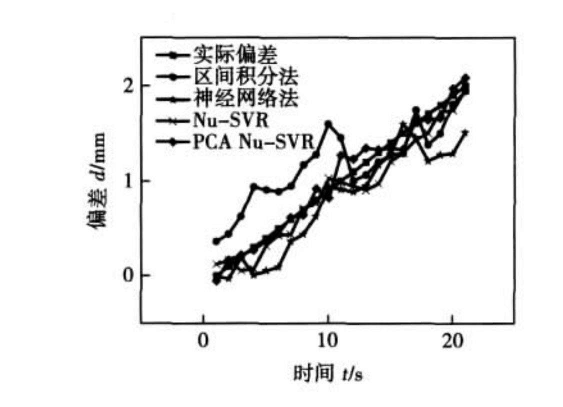

图 5 焊缝偏差识别结果

Fig. 5 Result of seam offset identification

表 2 焊缝偏差识别算法运行时间

Table 2 Run time of seam offset identified methods

算法	运行时间 t/ms	最大误差 d_{max}/mm	平均误差 d_{mse}/mm
区间积分法	10	1.15	0.84
神经网络法	40	0.99	0.75
Nu-SVR	43	0.94	0.65
PCA_Nu-SVR	15	0.95	0.65

4 结 论

提出基于 PCA_Nu-SVR 的水下焊缝偏差识别算法. 对基于旋转电弧传感器的水下焊接电流信号构建的样本数据集进行主成分分析,可以有效降低数据维数从而实现数据压缩; 通过 Nu-SVR 支持向量回归对降维后数据进行训练并进行识别试验. 结合 PCA 和 Nu-SVR 的算法能很好解决水下焊接电流信号的不稳定的问题,并提高 Nu-SVR 的运行速度,其精度与普通的支持向量机法相差不大,比区间积分法和神经网络法更高; 在运行速度上,比区间积分法慢,但比神经网络法和支持向量机更快.

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作者简介: 杜健辉,男,1981 年出生,博士. 主要从事材料加工与自动化研究. 发表论文 2 篇. Email: leoduba@qq.com aohong[3], WEI Yanhong[1,3] (1. State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China; 2. Shanghai Xin Li Institute of Power Equipment, Shanghai 200125, China; 3. School of Material Science and Technology, Nanjing University of Aeronautics & Astronautics, Nanjing 210016, China). p 17 – 20

Abstract: A software package has been developed which can simulate and predict the weld solidification cracks with three dimensional FEM. It consists of pre-processing, post-processing and solidification cracks predicting subsystem. The post-data treatment of software package for three-dimensional simulation and prediction of the weld solidification cracks can deal with the calculated results and display the results in featured curves, contours and 3D figures by combining graphic functions of softwares. The solidification cracks predicting subsystem regresses to the experimental data of trans-varestraint test (TVT) to obtain the material resistance curve of weld solidification cracks or reads the modified material resistance of simulating TVT from the database and has it compared with the one and thus predict the weld metal solidification cracks.

Key words: solidification cracking; post-data treatment; material resistance curve; driving force

Seam offset identification of underwater arc welding using PCA_Nu-SVR DU Jianhui, SHI Yonghua, WANG Guorong, HUANG Guoxing (South China University of Technology, School of Mechanical & Automotive Engineering, Guangzhou 510640, China). p 21 – 24

Abstract: In order to realize the underwater auto-welding based on rotating arc sensor and get high accuracy tracking, it is necessary to study the seam offset identification algorithm. First, the wavelet and median filter methods were used to process welding current signals, and then the signal was divided into cycle and normalized. PCA was used to remove the self-correlation of data set and reduce the number of inputs of Nu-SVR. The result showed that the maximum error and mean error of PCA_ Nu-SVR was 0.95 mm and 0.65 mm. The precision of PCA_ Nu-SVR was as good as Nu-SVR, and better than interval integral method and neural network. The runtime of PCA_ Nu-SVR was more than interval integral method, and less than neural network and Nu-SVR.

Key words: rotating arc sensor; underwater welding; principal component analysis; support vector regression; seam offset identification

Parameters control for interfacial fracture mode of resistance spot weld dual-phase steels YANG Haijun[1], ZHANG Yansong[1], LAI Xinmin[1], ZHANG Xiaoyun[2] (1. School of Mechanical Engineering, Shanghai Jiaotong University, Shanghai 200240, China; 2. Vehicle Manufacturing Engineering, Shanghai General Motors, Shanghai 201201, China). p 25 – 28

Abstract: In this paper, the response surface method is used to analyze the influence of welding parameters on the interfacial fracture mode of resistance spot welded (RSW) joint made of dual phase steel DP600 with 1.4 mm thickness. The results showed that welding current, welding time and holding pressure were the key parameters to the interfacial fracture mode of the RSW joints. The proper welding parameters can enlarge the weld nugget diameter ratio and reduce its sensitivity to welding parameters. The optimized welding parameters were obtained to control the interfacial fracture mode with the consideration of the robustness of welding process which was validated by experiments.

Key words: dual phase steel; interfacial fracture; improved response surface method; process optimization

Synthetic analysis about effect of GMAW arc to Nd: YAG laser transmitting WANG Wei, LIN Shangyang, WANG Xuyou, LEI Zhen (Harbin Welding Institute, Harbin 150080, China). p 29 – 32

Abstract: From the view of GMAW arc's absorption and refraction to Nd: YAG laser, the phenomena, which when Nd: YAG laser crosses GMAW arc, it's radius will decreases, was analyzed in this paper. The results show that if decreasing of Nd: YAG laser radius is due to absorption of GMAW arc totally, the absorptivity of pulse GMAW arc to Nd: YAG laser is 0.7%, and the absorptivity of short-circuiting GMAW arc is 2.0%. If this phenomena is attributed to refraction of GMAW arc overall, Nd: YAG laser beam is deflected 0.34% by pulse GMAW arc, and 1.02% by short-circuiting GMAW arc. But considering this phenomena form the view of welding, it can regard approximatively GMAW arc as no effect on Nd: YAG laser beam transmitting.

Key words: hybrid welding; laser welding; GMAW; laser absorption; laser refraction

Digital welder parameters self-regulating algorithm based on partial Newton interpolation LIN Fang[1,2], HUANG Wenchao[1], CHEN Xiaofeng[1], WEI Zhonghua[1], XUE Jiaxiang[1] (1. School of Mechanical & Automotive Engineering, South China University of Technology, Guangzhou 510640, China; 2. Department of Electromechanical Technology, Jiangmen Polytechnic, Jiangmen, Guangdong 529000, China). p 33 – 36

Abstract: A welding parameter self-regulating algorithm based on long-step calibration and partial Newton interpolation were put forward. By this algorithm, not only the unified parameters regulation could be realized, but also the database of the digital welder could be transformed from static mode into dynamic mode, in which the self-learning and self-regulating function were adopted. It might provide an effective strategy for the intelligent evolution of the digital welder. The results of the tests indicated that the welding parameters could be continuously self-regulated in a wide range. By the P-GMAW parameters generated by this algorithm, a stable welding process and well-formed seams could be acquired. By employing the parameter storing method with various priorities, the optimization of the parameters could be achieved.

Key words: digital welder; long-step calibration; partial Newton interpolation; self-regulating algorithm

Experimental investigation of ultra-assisted electrode sparkles depositing process ZHANG Pin[1], MA Lin[1,2], LIANG Zhijie[2] (1. Science and Technology Laboratory on Remanufacturing, Academy of Armored Force Engineering, Beijing 100072, China; 2. Institute of Chemical Defense, Beijing 102205, Chi-