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Sorting of Portable Small Metallic Components using Machine Learning Technique

Atul K. Joshi[a,*], **Balasaheb M. Patre**[b]

[a] *Department of Instrumentation Engineering, MKSSS' Cummins College of Engineering for Women, Pune 411052, India.*

[b] *Department of Instrumentation Engineering, SGGS Institute of Engineering and Technology, Nanded 431606, India.*

Abstract:

Modern auto-mobile industries have challenge of increasing manufacturing rate in order to meet the increasing demand of market. Auto-mobile uses plenty of small castings, fabricated components, and sub-assemblies. These components are required to be tested thoroughly before deployment. The parent production industry generally offloads this task to vendors. The quality control of these produced components plays vital role in this process. The use of Non-destructive testing (NDT) methods helps to accelerate production process to a greater extent. The NDT based on acoustic resonance facilitates to test products in-line. It follows the principle of acoustic resonance (AR). The component under test (CUT) is triggered by an impact or induced with a shock wave, and the acoustic response is acquired and analysed. In addition to this the weight and Brinell hardness (HB) of the same CUTs is also measured and documented. Hence every CUT has its unique signature composed of acoustic resonance frequency (ARF), weight and (HB) hardness number. The signatures of the CUTs are compared with the master component's signature. The result is used to detect faulty CUT on the basis of Go-NoGo decision. In this paper we have proposed, developed and tested the machine learning techniques which help to take the same decision quickly. The consistency of the method is tested on the set of similar components. The responses are tested by introducing a fault in a test-component. The results are useful to sort the CUTs in 'Go' and 'NoGo' class. The decision saves labour-cost and time.

Keywords: Non-destructive testing (NDT), Go-NoGo decision, Machine learning, Fault detection

INTRODUCTION

The metal cast-components are bit tricky to manufacture and sometimes cannot be repaired for deployment. There are possibilities of introduction of faults like blow holes, phase formations, inclusions, geometrical deformations in these cast-components during the casting process. It is necessary to test the integrity of the components before processing further in order to save labour cost and efforts. There are number of techniques adapted to test the components. The Non-Destructive Testing (NDT) methods are more popular then Destructive Testing (DT) methods because; the NDT methods can be adapted for in-line production process. The manual NDT methods have limitations on their use because of huge production rates. It may result in slowing down the production rates. There may be chance of human errors. The automation of NDT method is the key for elimination of most of the errors.

Now a days computer is becoming more popular in automation field. The computers are capable of handling and processing huge data in short time. The use of computers for machine learning is becoming very powerful tool for result/decision oriented processing of data. It is implemented in two phases. In the beginning, some feature vectors are found or decided to collect and make data sets. These data sets are divided in to training and testing data sets. Initially the computer is trained for processing and drawing notable inferences. In next phase the testing data set is provided to computer, and then it processes the same data set and draws results on the basis of the training data set. This process increases the accuracy of results. In addition to this it also accelerates the testing process. The Support Vector Machine (SVM) is one of the widely used and powerful tools in the field of machine learning. This method is versatile and it has wide range of applications.

In view of above said advantages and applicability of SVM, we have proposed, a technique for sorting of components under test (CUT) using SVM. The data set of different tests is gathered for a set of CUTs. The same set is used for training the computer for classifying the CUTs in to PASS (Go) and FAIL (NoGo). Brief outline of the paper is as follows: in section 2, a brief literature review of different SVM applications is covered. Section 3 focuses on the sorting of CUTs in to PASS (Go) or FAIL (NoGo) on the basis of test results. Section 4 deals with experimentation and result analysis which also highlights the applicability. The paper concludes with section 5.

LITERATURE REVIEW

Samper-Gonz et.al has used the machine learning technique and feature extraction method for classification of the Alzheimer's disease. They tested three different classification techniques (linear SVM, anatomically regularized SVM and multiple kernel learning SVM) and achieved highest accuracies.[1]

Tiwari R. et al. worked on framework and extracted the information of co-expression relationships among genes from the published literature using a supervised learning method. They used Dynamic Conditional Random Fields (DCRFs), for training the classification model their approach is based on

* *Correspondence author*

semantic analysis of text to classify the predicates describing co-expression instead of presence of keywords. They have also worked on different classification algorithm.[2]

Sharma D. et al. proposed an approach for network analysis for integration of topic modelling and social network analysis. Their team has collected 16,855 scientific papers from six top

Journals in the field of machine learning published for the period of 1997 to 2016 for analysis. Their results of experimentation highlights that the articles on network and published on largest scale during 2002 to 2006. [3]

According to Fabris F. et al. used machine learning approach to answer biological questions reflecting the complexities of the underlying ageing processes in animal's species. they also studied the findings and weaknesses of different papers based on supervised machine learning algorithms They have summarised their work detecting some bookmarker of animal ageing with the help of machine learning. In conclusion they agreed that the supervised machine learning has contributed to provide novel insights on animal ageing. [4]

Machine learning technique with wavelet transform is used for detection and sorting spikes from multi-unit recording by Quian R. et al. They have proposed improved method for spike detection by setting threshold for amplitude. The algorithm proposed by their team has performed better than the conventional methods for detection of spikes in recorded data [5]

Rasouli K. et al. have used the machine learning algorithms namely Gaussian process (GP), support vector regression (SVR), and Bayesian neural network (BNN) for weather forecasting with data generated by NOAA Global Forecasting System (GFS) model. It is referred for forecasting of daily stream-flow with 1 to 7 days lead time. They found that the BNN performs better as compared to multiple linear regression (MLR). Their conclusion showed that among various combinations of predictors, GFS and local observations are suitable for short lead times. on the other hand the climate indices and same local observations are referred for weather forecasting with longer lead times. The outcome of their study states that the GFS outputs and local meteo-hydrologic observations are the best predictors for weather forecasting.[6]

In agricultural environments, the mapping of broad land covers type based on image analysis approach is the area explored by Duro D. C. and his study group. They used three supervised machine learning algorithms namely random forest (RF), support vector machine (SVM) and decision tree (DT),for agricultural landscapes to classify broad land cover. the results of object-based and pixel-based classifications are not able to get statistically significant accuracies. The maps produced using DT algorithm compared to the maps produced by using SVM or RF showed significant difference in classification accuracies. Visually adequate depiction of crop land cover types, riparian and wetland, is provided by SVM and RF based classification algorithms.[7]

Tsanas A. and Xifara A. developed framework based on statistical machine learning approach in order to detect cooling load (CL) and heating load (HL) of residential buildings. They have selected 8 input variables namely glazing area distribution, orientation, overall height wall area, surface area, relative compactness, glazing area and roof area and output variables as HL and CL. Their investigation is based on variety of classical and non-parametric statistical analysis tools. Their work includes comparison of powerful state of the art non-linear non-parametric method, random forests, against the classical linear regression approach in order to estimate CL and HL of residential buildings. The conclusion of the study states that the approach of using machine learning tools is a convenient and accurate approach towards the estimation of residential building parameters.[8]

The primary objective of the study done by the team of Stojanova D. is to model the canopy cover in Slovenia and vegetation height by Landsat satellite data, integrating LiDAR data, and the use of machine learning techniques. The integration of the techniques uses the precision and accuracy of LiDAR data and the wide coverage of satellite data which helps to generate cost-effective realistic estimates of the vegetation height and canopy cover. They have applied several machine learning techniques for forest management and monitoring of continuous forest vegetation map. The result analysis of the team has proved that ensemble methods perform significantly better than single- and multi-target regression trees.[9]

The aim of the work done by Salvatore C. et al. is to check feasibility of a supervised machine learning algorithm for diagnosis of Parkinson's disease (PD) in patients with Progressive Supra-nuclear Palsy (PSP). The method is based on T1-weighted Magnetic Resonance Images (MRIs) of healthy control subjects, PSP patients and PD patients with 28 subjects of each class used for supervised machine learning algorithm based on the combination of Principal Components Analysis (PCA) as feature extraction technique and on Support Vector Machines (SVM) as classification algorithm. The results of the algorithm allowed individual diagnosis of PD versus controls, PSP versus controls and PSP versus PD with an enhanced accuracy. In conclusion, the application of computer-based diagnosis gives encouraging results in clinical practice.[10]

Now a days on-line marketing applications has a software support which suggests the products, contents to potential users and services. Collaborative filtering (CF) is a one of the successful recommendation paradigm which refers the transaction details to enrich user and item features for recommendation. The graphical relation between the user-item interaction and transactions helps in link prediction problem. The advantage of the graphical structure is to capture subtle information of relations between items and users. Xin Li and Chen H. has proposed a kernel-based recommendation approach and designed a novel graph kernel that refers the items selected by customers and predicts whether there may be a link. They have proven validity of the kernel and applied to single class classification framework for recommendation and evaluated the approach with three real-world datasets. They claimed that the proposed method performs better than the state-of-the-art benchmark algorithms.[11]

Khandani A. E. et al. took a novel approach to use machine learning method to construct consumer credit risk model. They have used credit bureau data from January 2005 to April 2009 and customer transactions. They have claimed that they are able to construct out-of-sample forecasts which significantly improve the classification rates of credit-card-holder.[12] It is seen that, there is a wide variability in visual appearance of traffic signs in real world. It is affected by the varying weather conditions, changes of illumination, partial occlusions. In practice it is required to recognize large number of different traffic signs with higher accuracy. Classifying different traffic signs using pattern recognition technique is still a challenging problem for computer systems. It uses both machine learning techniques and image processing and is continuously refined. Stallkamp J. et al. used the Convolutional neural networks (CNNs) for tackling the same problem. It has shown high accuracy of classification.[13]

Huang G. B. et al. worked on Extreme learning machine (ELM). It is used in regression applications as well as in large dataset (and/or multi-label) classification applications and it has shown good performance. In their work they have further applied ELM for classification for optimization of standard methods and extended the work to specific type of "generalized" SLFNs—support vector network. They have shown that the SVM's maximal margin property and the minimal norm of weights theory of feed-forward neural networks are actually consistent. They have also shown that the ELM has less optimization constraints due to its special separability feature as compared to the standard optimization method. In comparison with traditional SVM's and ELM for classification, the ELM tends to achieve better generalization performance. Classification with ELM is less sensitive to user specified parameters and can be easily implementable.[14]

Utility of Internet is better but it contains some risks like network attacks. The detection of intrusion is one of the major problem. Detecting and identifying the source intrusion is a serious problem as far as security of internal networks is concerned. In the paper of Tsai C. F. et al. they have tried various methods of machine learning techniques. They have studied around 55 cases in the period of 7 years from 2000. The study was focused on developing a unique and ensemble classifier. There are some limitations but the work provides some future directions for research.[15]

Sidorov G. et al. discussed a concept of syntactic n-grams (sn-grams). It is in the different from of construction as far as the neighbour elements are considered. In syntactic trees, the neighbours are taken by following syntactic relations instead of the text which appears in word. The machine learning methods are capable of bringing syntactic knowledge. Their work is focused on authorship attribution using sn-grams. The paper covers basic approach of traditional n-grams of words, tags, characters and part of speech (POS). The work highlights the use of support vector machines (SVM), Tree classifier J48, Naive Bayes (NB). Their work concludes that the SVM classifier shows better results.[16]

It is well known fact that the cancer is a heterogeneous disease which belongs to multiple subtypes. The early detection of cancer and prognosis of a cancer type is need of an hour in the field of cancer research. It is very important to classify the type of cancer in order to treat the patient and to facilitate the subsequent clinical management. Many research groups are keen about biomedical and the bio-informatics field in order to classify the types of cancers in to high or low risk groups. Machine learning (ML)is one of the deployable tool in real time scenario. It has ability to detect key features from complex datasets. The team-work of Kourou K. et al. is focused on use of ML to employ in the modelling of cancer progression. The discussed predictive model employed various supervised ML techniques with set of different input features and data samples.[17]

Acoustic Resonance testing of CUT

There are various NDT methods for testing small metallic and non-metallic castings. In case of producing large volume of identical components/articles, the mass production process is preferred. The standards like DIN-ISO 9000 require both demonstrated and documented product quality to satisfy the subjective and destructive testing of the sampled component/article. This leads the manufacturer to follow cumbersome and costly technologies and lengthy procedures.[18] The Acoustic Resonance Testing (ART) is one of the upcoming techniques which is suitable for in-line testing of components/articles. The component under test (CUT) is triggered by an impact or a shock wave. The acoustic response of CUT is acquired and analysed. The components having identical physical properties possess unique signature of the acoustic response. The ART method is fast, accurate and low cost hence ideally suitable for 100% testing and inspection.

Basic Principle

When an object is impacted, it tends to resonate in natural modes. The phenomenon is well understood by considering a simple case of an object with single degree of freedom (SDOF). The object will resonate at a fundamental frequency. This fundamental frequency is set by the equation (1)

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad (1)$$

where f_n=fundamental frequency, k =elastic constant, m = mass

Equation (1) shows that the fundamental/natural resonant frequency of the object or CUT depends on the

mass and the elastic constant of the object. Thus if there is a change in either of the two parameters there is a corresponding shift in the resonant frequency which can be observed in its acoustic response. This concept is applicable for an object with multiple degrees of freedom. It means that the object will have multiple resonant modes, each with a unique shape and resonant frequency. This resonance produces an acoustic response.

This response is like a signature of the object and any defects or deformities in the object can be detected due to the

variation in this response. In case of mass production industries, a master or a standard component is produced in the beginning. The signature of a master component is acquired in and the same is referred as a model dataset and the response of the CUT is compared with it. The degree of matching of the signatures is treated as a measure of acceptance. The result of the comparison is used for assigning classes to the CUTs as PASS (Go) or FAIL (No-Go). It is found that the resonant frequency exhibits the same dependency on mass and elastic constant.[19]

Thus in case of metal castings, the change due to porosity and blow-holes causes decrease in mass. A crack or discontinuity in casting changes the elastic constant. These facts affect the overall spectrum of the cast component i.e. CUT.

In proposed system, an acoustic response of the CUTs is acquired and stored in a computer using acoustic pick-up and data acquisition system (DAS). The stored time domain information is then converted in to frequency domain. The spectrum showed the peaks of the natural frequency of resonant modes of the CUT. The spectrum analysis of the master component and various samples of CUT showed the clear difference in their spectral signatures. The difference is used as a tool for detection of faulty CUT which facilitated to sort the CUT in the classes namely PASS(Go) or FAIL(No-Go)

Support Vector Machine (SVM) as a classification tool for CUT

SVM is well known machine learning method. The principle of SVM is based on simple linear classification. Equation (2) represents a generic linear classifier with x as the input vector.[20]

$$h_{w,b}(x) = g(w^T + b) \quad (2)$$

where $g(z) = 1$ if $z \geq 0$ and $z \geq -1$ otherwise

The optimization problem in linear classifiers can be stated as follows where we want to find the hyper plane that optimally divides the two classes. Where x is the input vector and w is the set of weights that we need to optimize. The geometric margin $\boldsymbol{\gamma}$ is defined as the decision boundary in the feature space and the distance between the sample point.

$$m \quad in_{\gamma,\omega,b} \ \frac{1}{2} \|w\|^2 \quad (3)$$

Where $y^{(i)}\left(w^T x^{(i)} + b\right) \geq 1, i = 1,2 \ldots\ldots m$

The optimized problem is simplified to

$$w^T x + b = \sum_{i=1}^{n} \alpha_i \, y^{(i)}\left(x^{(i)}, x\right) + b \quad (4)$$

Thus we can see that after calculation of α_i , the expression reduces to a calculation of inner product between support vectors and the new point x. Thus every new point can be classified easily by just computing the inner product only. A mapping function $\phi(x)$ maps the data from input space to a feature space. The inner product in equation (4) can be replaced with the kernel function in equation (5)

$$K(x,z) = \phi(x)^T \phi(z) \quad (5)$$

It shows that selection an optimal kernel function; any non-linear classification problem can be solved using SVM.

Using SVM for ART of CUT

The ART of CUT represents the acoustic resonance frequency spectrum. The main features of the spectrum are amplitude and the location of peak frequency. The SVM can be trained by applying inputs like sum of the amplitudes in the region of interest and the range of frequency spectrum. A suitable kernel is chosen from a variety of kernels such as quadratic, linear, radial basis function depending on the application. The data of a large number of training samples with a proportionate number of ``ok" samples (PASS (Go)) and defective (FAIL (No-Go)) samples is referred. The SVM is trained with the input set of data. Different kernel functions and feature vectors are used to find the optimum method.

Experimental Test set-up

The testing was carried out on a batch of 144 tubular-components of mild steel having similar geometry. These components are barrel pieces of seamless tube and refereed as CUT. All the CUTs of the batch are checked and selected for dimensional similarity. The acceptability of the CUTs depends on certain parameters of CUTs. These parameters are referred to as feature vectors. The proposed experimental set-up uses three feature vectors namely Weight, hardness and ARF, for sorting the CUTs in to PASS(Go) and FAIL(No-Go) classes. The measured data of these feature vectors is documented for sorting of the CUTs. The weight of each CUT is measured using the set-up as shown in Figure 1. The hardness of the CUTs is measured by using Rockewll hardness tester in Brinell hardness (HB) scale as in Figure 2 and the acoustic resonance frequency (ARF) data of all the CUTs is acquired by using the measurement set-up as shown in Figure 3. The data of all three feature vectors is graphically presented in Figure 4.

Figure 1: The photograph of weight measurement set-up

The testing is done by using WEKA (version 3.9.2). It is a popular machine learning and analysis software.[21] The measurement results of feature vectors are documented in respective .csv file. The same file is then converted in to .arf file for further processing.

Table 1: Results of 3 features

Training Testing	Training			Testing			Confusion Matrix		SVM classifier
	Pass	Fail	Total	Pass	Fail	Total			
60-40	70	15	85	48	11	59	03	08	86.4407
							00	48	
80-20	92	20	114	24	6	30	02	04	86.6667
							00	24	
90-10	106	23	129	12	3	15	01	02	86.6667
							00	12	

Figure 2. Hardness test set-up

Figure 3. ART set-up

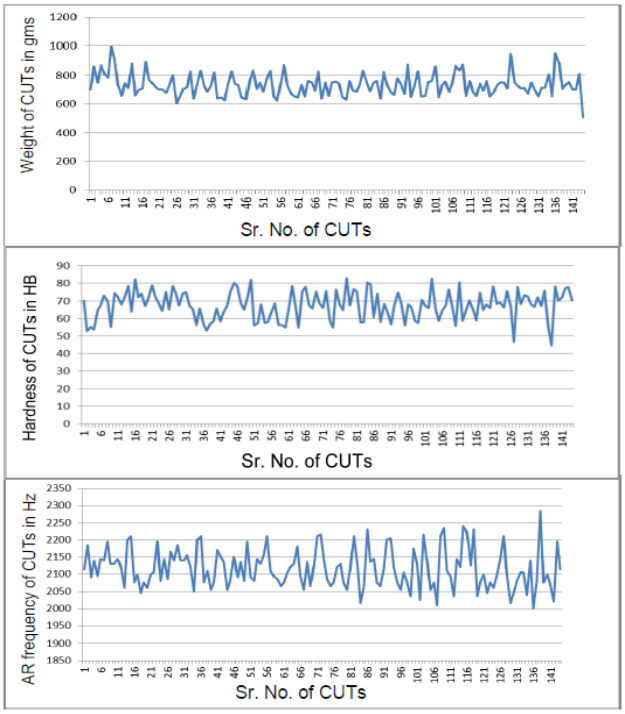

Figure 4: Test data of CUTs

Table 2 : Comparison of accuracies for different classifiers

Classifier	SVM		Baysen		knn		Random Forest	
Accuracy	86.6667		96.6667		100		100	
Confusion matrix	2	4	5	1	6	0	6	0
	0	24	0	24	0	24	0	24

RESULT ANALYSIS

It can be seen that the measurement of weight and ARF is a whole-part testing phenomena. Where hardness is a space selective phenomenon. The selection of feature vectors is dependent on deployment of the CUT. The test result of 3 feature vectors for SVM is shown in Table 1. It is clear that the accuracy is maximum for training-testing split-up of 80-20 and 90-10 hence, the split-up of 80-20 is preferred for testing accuracy of other classifiers

The comparison of accuracies for 4 classifiers namely SVM, Baysen, KNN and Random-Forest is documented in Table 2. The result in Table 2 shows that the accuracy of KNN and Random-Forest is 100%.

CONCLUSION

The CUTs are sorted by using 3 feature vectors. The results in Table 2 show that the best accuracy of sorting is achieved with KNN and Random-Forest classifiers. The feature vector and sorting class for the CUTs is selected according to the expected purpose of the CUT.

The measurement of parameters and documentation in .csv file can be automated for respective feature vectors. The same file is then imported in to the WEKA test environment for testing and analysis purpose. It helps to accelerate the process of sorting. Smartly selected feature vectors can reduce the testing time of process.

In case of above experimentation, it can be seen that the ARF of the CUT is dependent on the metallurgical and physical properties of the CUT. Hence ARF data of CUTs as only one feature-vector may suffice for the sorting process. It will also accelerate the sorting process.

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