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A frequency assessment expert system of piezoelectric transducers in paucity of data

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Abstract

It is difficult to measure in the laboratory the operating frequency of a piezoelectric transducer that is a kind of electric equipment. Some simulation methods were developed for this frequency calculation, but were still complex to perform. With high learning accuracy, a Frequency Assessment Expert System of Piezoelectric Transducers (FAESPT) is developed in this study to assess the frequency easily. FAESPT is based on mega-fuzzification that is a method to increase the learning accuracy with fuzzy neural network for the small data-set environment. In this article, FAESPT is established and its assessment accuracy is compared with traditional neural network and neuro-fuzzy method. The results indicate that FAESPT can easy to assess the frequency of a transducer and get good learning accuracy in the environment of the paucity of data.

Keywords: FAESPT; Expert system; Mega-fuzzification; Machine learning

1. Introduction

This study presents a Frequency Assessment Expert System of Piezoelectric Transducers (FAESPT) to assess the frequency of piezoelectric transducers instead of laboratory experiments. A piezoelectric transducer is a key acoustical element to transmit and receive sound wave in the water. The measure of the frequency value in the laboratory experiment is hard to perform and has to take a longtime. Even though there are some electric simulation models to calculate the values, they are still too complex to perform. These will be obstacles for the assessment of the operating frequency. Hence, in this study, machine learning methodologies that have been used to predict or evaluate data are applied to establish an expert system for the transducer frequency estimation.

Acoustical waves can be transmitted longer from a transmitter than electromagnetic waves do in underwater. By transmitting a sound wave from the transducers, the surface or underwater objects ranging several miles away from the transducers can be located by detected the reflected sound wave from the objects itself. Up to now, the Langevin type piezoelectric transducer is still the best candidate as acoustical telemetry transmitters. The operating frequency of the transducer determines the distance that the sound wave could travel and is important to measure it.

A Langevin type piezoelectric transducer is structured as Fig. 1. The device consists of a stack of eight PZT4 ring transducer elements electrically connected in parallel, a steel tail mass, a flared aluminum head mass and a steel compression bolt (Stansfield, 1990). The differences of head mass and tail mass determine different resonance frequency of a transducer. As well as the proposed method in this research assess the frequency using head mass and tail mass. Many designs of the Langevin type transducer have been reported in many literatures (Inoue, Sasak, Miyama, Sugiuchi, & Takahashi, 1987; Krimholtz, Leedom, & Matthaei, 1970; Mccammon, 1980). The design of the transducer involves many physical parameters such as the area and thickness of the radiating surface, head and tail

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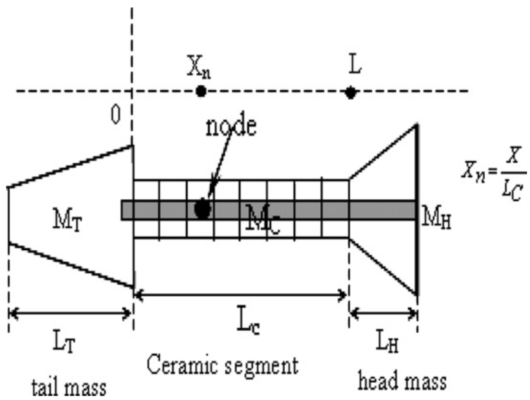

Fig. 1. The diagram of Langevin type transducer cross-section.

masses, ceramic volume and prestress rod, to meet the requirements of operating frequency, bandwidth, and transmitting and receiving frequency responses.

Two problems are raised in the assessment of the transducer frequency applying machine learning method: one is the accuracy of the assessment value, the other is the paucity of the present data. Because the present data are limited, the estimation accuracy will not be good and we need to build more measured data. To deal with this problem, FAESPT that is based on the Mega-fuzzification method developed by Li, Wu, and Chang (2005, 2006) and Chang (2005) is used in this study. The Mega-fuzzification aims at providing better prediction accuracy under the condition of limited learning data size. There are many machine learning methods have been developed in the field of artificial intelligence. In them, fuzzy methods have better accuracy than traditional neural ones (Li et al., 2005), and Mega-fuzzification has the best prediction accuracy in all of them (Chang, 2005; Li et al., 2005, 2006). Data on hand may be not limited. However, because Mega-fuzzification is designed to improve learning accuracy, it gets better learning result than general fuzzy methods. At the beginning, the Mega-fuzzification method is proposed for the production strategy of a flexible manufacturing system (FMS) (Li et al., 2005, 2006). It is also successful applied in the economical index forecast (Chang, 2006). As well as based on this method, FAESPT is used to assess the transducer frequency values in the field of electrics instead of laboratory experiments in this research.

2. Learning derived from limited data

For limited data, data distribution, mean, and variant are unknown and they can not predicted by statistics methods. However, in many real cases, prediction has to be done although current data are not enough. Many researches used machine learning methods to solve this kind of problems in paucity of data, but most of them relied on a great deal of data for learning. There are only few studies for learning in paucity of data or small data size. The follows review some researches about learning derived from limited data.

Early in Anthony and Biggs (1997), some characters of computational learning are researched. Machine learning problems, such as data size needed for good learning, times of learning for better accuracy, and estimation of error are described theoretically. Although (Anthony & Biggs, 1997) did not offer practical methods to solve problems, researches in Anthony and Biggs (1997) provide some models to define the mathematical ranges as the answers of above problems. For the data size needed for good learning, (Anthony & Biggs, 1997) modeled it as

$$m \geqslant \frac{1}{\varepsilon}\left(\ln|H| + \ln\left(\frac{1}{\delta}\right)\right) \tag{1}$$

where H is the hypothesis of a finite example space, and the probability is greater than $(1-\delta)$ that the error is less than ε. Under desired values of ε and δ, Eq. (1) is a range of the number of training examples for any consistent successful learner to any target concept in H. However, (Anthony & Biggs, 1997) also pointed out that $|H|$ is hard to count in most cases, and ε and δ are difficult to determine also. In brief, computational learning theory offered theoretical answers for machine learning but did not provide actual method to improve learning results.

Later, a useful concept named virtual samples was proposed by Niyogi, Girosi, and Tomaso (1998) for better learning results in paucity of data. Virtual samples method added some artificial data to the system in order to increase recognitionability in pattern recognition. Virtual samples were generated by mathematical transformations. The research of Niyogi et al. (1998) indicated that a learning machine can verify an instance more precisely with virtual samples.

Besides, information diffusion (Huang, 1997) is another method to improve learning accuracy by statistics knowledge. In the relative research, Huang and Moraga (2004) in advanced proposed the diffusion-neural-network (DNN) that combines the principle of information diffusion and a traditional neural network for function learning. According to the results of their numerical experiments, the DNN improved the accuracy of the back-propagation neural networks (BPNN). Huang and Moraga proposed a concept that the new artificial examples were used to fill the information gaps caused by data incompleteness.

Furthermore, Li, Chen, and Lin (2003) invented the functional virtual population (FVP) approach following the adding virtual samples concept. Using their method, virtual samples are generated as an assistance to improve the FMS scheduling knowledge in small data set learning. In their study, only a small amount of data was obtained for learning. Then the FVP method expanded the system attribute ranges and added some virtual samples. After artificial neural network (ANN) learning, FVP improved the scheduling knowledge.

Recently, similar to the principle of adding some data to the system, the concept of the continuous data band was proposed by Li et al. (2005, 2006) in their Mega-fuzzification method to improve flexible manufacturing system