A Fractal-ANN approach for quality control

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Abstract

The main problem with modern quality control of sound speakers is that the process is conducted manually. This manual checking of the quality of sound speakers is time consuming. In order to find an automated way of doing this, this paper presents an intelligent system for automated quality control in sound speaker manufacturing, which fuses Fractal Dimension (FD) into Artificial Neural Networks (ANNs) system. The Artificial Neural Networks is used to classify the levels of the quality of sound speakers from SEAS, a Norwegian manufacturing company for sound speakers. The Fractal Dimension is used for reducing the complexity of the sound signals.

Keywords: Fractal Dimension, Quality Control, Artificial Neural Networks

1. Introduction

The main problem with modern quality control of sound speakers is that the process is conducted in partial manually. [3] This manual checking of the quality of sound speakers is time consuming. In order to find an automated way of doing this, research has been done almost for 20 years without substantial success. [8] This project is related to an industrial project conducted in a Norwegian company SEAS [12] and the purpose of the project is to establish an automatic quality control process. An intelligent system for automated quality control in sound speaker manufacturing has been developed. An Artificial Neural Network model has been used for learning the experience of quality control for making a quality decision using a real time series of measured sounds signals. The Fractal Dimension (FD) is applied for reducing the complexity of the sound signals. The experiment results show that the intelligent system developed increases the efficiency of the quality control.

This paper is organized as the follows: Section 1 introduces the background, general approaches and the benefits of the intelligent approach. Section 2 describes the problem of quality control of sound speakers manufacturing. Section 3 presents a method how to calculate Fractal Dimension. An ANN model for classification of the levels of quality of sound speakers is presented in Section 4. Section 5 shows an integrated system structure of the fractal-ANN approach. The implementation and experimental results are discussed in Section 6. Conclusions are drawn in Section 7.

2. Description of the problem

The basic problem of the quality evaluation of the speakers is to identify the sound signal pattern. This requires a comparison between the real measured sound pattern and reference (ideal good) sound signal. The good or accepted speaker should be of the characteristics which are not different much from the reference one. A Log Sine Swept (LSS) signal shown in Fig. 1 is used as testing signal in the project. It is possible to compute the other important parameters necessary in sound speakers testing, such as Impulse Response (IR) and Frequency Response (FR) form the LSS signal. In this project, the LSS real time series signal is directly used as the input to the integrated intelligent system.

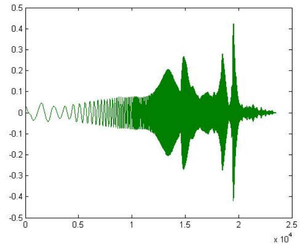

Fig. 1. LSS sound signal of a good speaker.

3. Fractal Dimension

Fractal geometry is a term originally coined by Polish born mathematician Benoit Mandelbrot [9] in his book *"Fractals: Form, chance and dimension"*. With a wide spectre of applications, there is an increasing interest for exploring new applications of fractal geometry and Fractal Dimension to industries. The Fractal Dimension is part of fractal geometry and it can be calculated using the box counting methodology [13]. Given a non-empty bounded set, *S*, covered with boxes of size ε , as illustrated in Fig. 2 with the corresponding correlations where $N(\varepsilon)$ is the number of non-empty boxes covering the set.

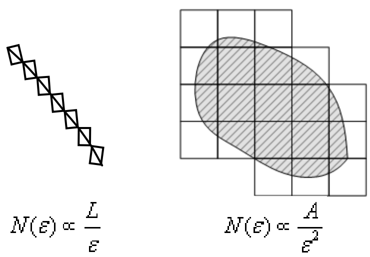

Fig. 2. Illustration of two sets covered by boxes; the left one a 1-D set and the right one a 2-D set.

Let *S* be a subset of a *D*-dimensional Euclidean space and let $N(\varepsilon)$ is the minimum number of D-dimensional cubes of size need to cover *S*. It would be interesting to see how $N(\varepsilon)$ depends on ε . As illustrated in Fig. 2, the relationships are shown: For a smooth curve with length *L*, the relationship is $N(\varepsilon) \propto L/\varepsilon$ (left); and for a planar region of area A bounded by a smooth curve, the relationship is $N(\varepsilon) \propto A/\varepsilon^2$ (right). The key observation is that the topological dimension of the sets equals the exponent *d* in the power law:

$$N(\varepsilon) = k(1/\varepsilon)^d \tag{1}$$

where *k* is a constant. For most fractal sets *S*, this power law is valid though *d* is no longer an integer. For fractal sets *S*, *d* is interpreted as a dimension, and usually called the capacity or box dimension of *S*. By taking log on both sides, a log-log function is obtained as the following:

$$\log(N(\varepsilon)) = \log(k) + d\log(1/\varepsilon) \tag{2}$$

The Fractal Dimension *d* of an fractal set in a metric space is given by the formula by taking the limit value $\varepsilon \to 0$:

$$d = \lim_{\varepsilon \to 0} \frac{\log(N(\varepsilon))}{\log(1/\varepsilon)}, \text{ if the limit exists} \tag{3}$$

It should be noted that it is possible to compute Fractal Dimension using analytic methods like the formula described above. The experimental technique for box-counting methods is an easy way to compute FD. Counting the number of boxes for different size of ε and performing a logarithmic linear regression, we can estimate the FD of a geometrical object with Equation 2. This algorithm is illustrated in Fig. 3.

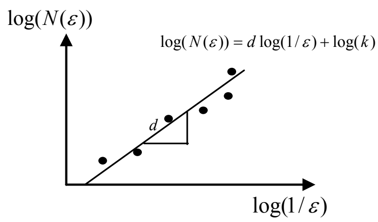

Fig. 3. Logarithmic regression to compute FD.

This is the mathematical definition of the box counting dimension. There are various types of calculations found in various university campus sites. Usually the box counting dimension is estimated through a logarithmic regression using a log-log curve with simple calculus. This is also the method used for the experiments with the software FracLab [4] applied in MATLAB package.

The FD itself can be viewed as an indicator (feature) for most practical purposes; it describes the fractal characteristics of a set. In the case of a sound signal, the FD can be seen as an indicator (feature) towards the "roughness" of the output signal produced from a sound speaker. This is the reason for why the FD has been thought of in relations to sound signals; it can be used to indicate a pattern in very complex signals. FD has been successfully used in other industrial applications such as fabric quality control and to analyze metallic surface features. [2], [7], [11]

4. Artificial Neural Networks

Artificial Neural Networks (ANNs) have been used extensively in design and manufacturing. [1], [5], [6], [15] ANN is a model that emulates a biological neural network. It consists of Processing Elements (PEs), called neurons, and connections between PEs, called links. Associated with each link is a weight. Multiple Layer Perceptron (MLP) ANN trained by Back-propagation (BP) algorithm is one of the most popular and versatile types of ANN. It can deal with nonlinear models with high accuracy. A three-layer supervised learning ANN consisting of input layer, hidden layer and output layer is used as an identifying model in this study.

The Process Elements (PEs) are organized in different ways to form the network structure. Each PE operates by taking the sum of its weighted input and passing the result through a nonlinear activation function, mathematically modeled as

$$y_i = f(a_i) = f_i(\sum_{j=1}^{n} w_{ij} - s_i)$$

The error is subsequently backward propagated through the network to adjust the weights of the connections and threshold, minimizing the sum of the mean squared error in output layer. The ANN computes the weighted connection, minimizing the total mean square error between the actual output of the ANN and the target output. The weights are adjusted in the presence of momentum by

$$(w_{ji})_{n+1} = (w_{ji})_n + \Delta w_{ji}$$

$$\Delta w_{ji}(n+1) = \eta \delta_j x_i + \alpha \Delta w_{ji}(n)$$

where η is learn rate, δ_j is an error value for node j and α is a momentum term. The momentum term is added to accelerate convergence. [14]

5. Fractal-ANN approach

The new intelligent approach of quality control of speakers consists in the integration of Fractal Dimension (FD) computing the features of sound signals and ANNs classifier for the quality evaluation of the sound speakers. Fig. 4 shows how the approach functions, starting from the sample of LSS signals of the sound speakers produced in the company and ending to the final evaluation of the quality of speakers. The intelligent system mainly includes the FD computation model and the SBP ANN model. FD and ANN model has been discussed in section 3 and 4 respectively.

The way of estimating the FD was found in a project conducted the autumn of 2005. It is very difficult to spot any patterns in the FD alone and therefore the motivation to develop a computational intelligence model to evaluate and find any patterns in order to classify the quality of a given driver. So a main point of this project is to integrate the work conducted in the project work into a larger scale model where the output is the quality of the driver.

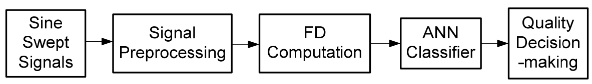

Fig. 4. System structure of the intelligent system.

The quality evaluation is already a somewhat complicated process at SEAS as it is. It would be pointless to propose a system of quality control that is more complicated than what already exists. Fig. 4 illustrates the structure of the intelligent system, which contains the following processes:

- *Input sine swept signal to sound speakers:* This is the generation of the test signal, the sine swept signal, to the sound speakers which is generated by connecting the driver to a computer. The signal is sent to the speaker and produces an output from the speaker in the shape of a sound.
- *Signal processing:* This process catches the output sound signals from the speaker and uses a transfer function in order to process it. The output is recorded with a microphone, which is

connected to a computer that calculates the transfer function to find the relationship between input and output. The computer stores the list of points in the output sine swept signal and from this a graph is generated. This graph in turn is the key for the next process.

- *Fractal Dimension computation:* The graph output from the previous process is used in this step to estimate the box counting dimension. This is done by the method described in section 3. The output of the fractal dimension alone is just a number and before the next step, it is necessary with the fractal dimension for the test speaker and the difference in fractal dimension between the test speaker and a reference speaker. This data pair is the input of SBP ANN model in the next step of the procedure.
- *SBP ANN model:* In this project a Standard Back-Propagation (SBP) ANN model has been developed using Neuframe development tool [10]. It can be trained and tested using the given data sets. Assuming a system for a future quality control of sound speakers, it would be necessary with pre-defined models for the various speakers. These models would be trained prior to testing any speaker so that the two parameters, FD and the difference in FD are entered directly into the model and queried. This generates an output in the shape of a quality level from the model.
- *Quality decision-making:* The SBP model produces an output in the shape of a quality level, which will be explained later on. This quality level is expressed in the form of a linguistic code or letter. Once this is presented to the user of the system, an expert evaluation of the output must be performed in order to verify this output. This can for example be done by evaluating the difference in FD of the tested speaker and the reference speaker to check that the output makes sense intuitively.

This is the main framework that both describes how the system works in the project, but also gives the main outline for how a future completely integrated system could work. Though the current model is quite fast to produce an output once the system has been trained, more work must be done on speeding up and optimizing this further.

6. Implementation and Experimental Results

All testing speakers are manufactured by SEAS factory and were conducted at SEAS' sound lab. The quality of sound speakers was classified into 4 levels by qualified test personnel at SEAS. These four levels are shown in Table 1. These quality levels were used in this paper.

Table 1
Speaker quality classification

	Quality level	Code
1	Excellent	a
2	Good	b
3	Mediocre	c
4	Bad	d

All sound speakers were tested following the same test routine in a sound proof chamber providing a Log Sine Sweep by using WinMLS. In each level, it should include one speaker with flawless good quality and it was selected as reference one. The resulting graphs of LSS without any grids were adapted in MATLAB where Fraclab was used to compute FD using box-counting approach. (see Fig. 5 and Fig. 6) It is pre-processed in Matlab better than to be processed directly in FracLab. It is important to have the correct type of datasets in SBP model. The structure of SBP model in Neuframe is shown in Fig. 7.

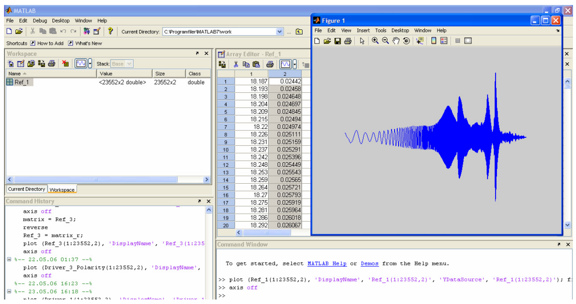

Fig. 5. Data points and figure display in Matlab.

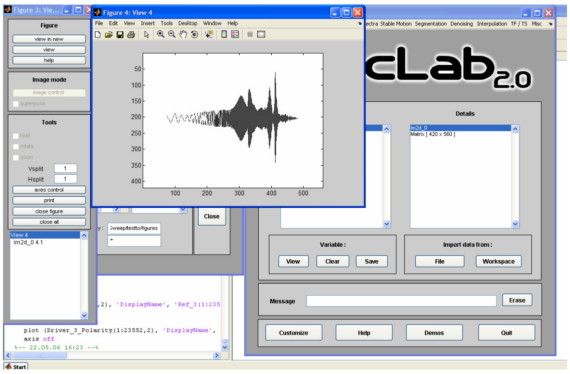

Fig. 6. File imported to FracLab and adapted.

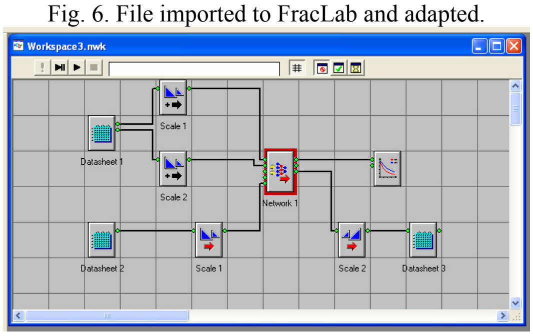

Fig. 7. The window of SBP model in *NeuFrame* development tool.

The two input variables of the SBP ANN model are defined as: FD of the signals and the Difference between a given signal and the good one. Output variable of the SBP model is the quality level of sound speakers.

Once the different class level had been determined and all the data pairs of FD and the difference in FD were assigned. 40 datasets were used for the training process and another 8 datasets were used for querying process. A part of training datasets is presented in Table 2.

Table 2
Training data sets

Driver Name	FD	Difference	Level
Driver_1	1,7472	0,0007	a
Driver_1_2	1,7465	0	a
Driver_2_rnb_thd_added	1,7457	-0,0008	a
Driver_4	1,7472	0,0007	a
Driver_7	1,7525	0,006	a
Ref_2	1,7465	0	a
Ref_1	1,7465	0	a
Driver_3_1	1,7484	0,0019	b
Driver_8	1,7483	0,0018	b
Driver_2_1	1,7486	0,0021	c
Driver_3_rnb_added	1,7491	0,0026	c
Driver_5	1,7491	0,0026	c
Driver_6	1,7487	0,0022	c
Ref_3	1,7489	0,0024	c
Driver_9	1,7516	0,0051	d
Driver_7_rnb_added	1,7518	0,0053	d
Driver_3_2	1,7508	0,0043	d
Driver_3_Polarity	1,7497	0,0032	d
Driver_1_rnb_added	1,7527	0,0062	d
Driver_2	1,7506	0,0041	d
Driver_3	1,7504	0,0039	d

After the process of training, 8 sound speakers with known classification given by an expert in the company were used for querying process. Table 3 shows the result of the experiment. The accuracy rate is about 88% in the experiment. It can be higher if we use more samples to training the ANN model.

It is interesting to notice that there is a substantial difference FD between the good reference speaker and the others. This indicates that the FD is an interesting mathematical concept for sound speaker quality control.

Table 3
The result of the experiment (quality classification: a – excellent, b – good, c – mediocre and d – bad).

# Label	Expected	SBP Output	Fractal Dimension	Difference
1	b	b	1,7482	0,0017
2	d	c	1,7495	0,0030
3	d	d	1,7501	0,0036
4	a	a	1,7466	0,0001
5	a	a	1,7473	0,0008
6	b	b	1,7482	0,0017
7	a	a	1,7455	0,0010
8	c	c	1,7488	0,0023

7. Conclusions

This intelligent approach is to integrate Fractal Dimension and Artificial Neural Network techniques in order to classify the quality of sound speakers automatically. It uses MATLAB to estimate the FD by the third party software FracLab, and then the output of this calculation is sent into a SBP ANN model with *Neuframe* development tool. The result has showed promise for the quality determination of a sound speaker.

Clearly, there are many advantages of using Fractal-ANN systems, including the following: (1). It is a general framework that combines FD and ANN techniques; (2). By using FD, the complexity of input signals can be reduced into just a numerical number between 1 and 2; (3). By using ANNs, the system can learn from the sample signals and classify the testing signals easily. Other benefits of the ANN technique also include its nonlinear ability, its capacity for fast learning from numerical and its adaptability. (4). It is a novel approach based on complexity science.

A framework for designing an automated quality control system for sound speakers has also been developed. It is recommended that this should be done in collaboration with a software developer company that specializes in speaker testing software such as Klippel. Furthermore the advantages of finding an automated quality control have been outlined along with possible measures that include the techniques used in this project.

There is little research available that focus on the use of fractal theory and intelligent techniques in sound speaker quality control. Therefore the work presented here presents a new intelligent approach to this problem that also shows a lot of promise.

Acknowledgments

The author is a member of the EU-fund FP6 Network of Excellence for Innovative Production Machines and Systems (I*PROMS) and would like to thank Olav Mellum Arntzen from SEAS Fabrikker AS and Trond Underland Berntzen from NTNU for collecting and testing the sample data.

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