DEVELOPMENT OF ARTIFICIAL INTELLIGENCE MODELS FOR PREDICTING NOISE LEVEL IN TYPICAL INDUSTRIAL WORKROOMS

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Noise prediction techniques are considered to be an important tool for evaluating cost-effective noise control measures so that, more acceptable situations can be finally obtained in workrooms. One of the most important issues in this regard is the development of accurate methods for analysis of the complex relationships among acoustic features affecting noise level in workrooms. In this study, artificial neural networks and advanced fuzzy techniques were employed to develop relatively accurate models for noise prediction in noisy industrial workrooms. The main acoustic features and noise levels were determined from 60 embroidery workrooms. Prediction errors, of all structures associated with networks and fuzzy models were approximately similar and within the acceptable level (lower than one dB). Neuro-fuzzy model could slightly improve the accuracy of noise prediction compared with networks. The results confirmed that the developed models as useful tools give professionals the opportunity to have an optimum decision about the effectiveness of acoustic treatment scenarios in embroidery workrooms.

1. Introduction

The basic element of hearing conservation program is predicting and determining the noise level, which can help to find the most cost-effective noise control measures. Prediction of noise induced by industrial processes, especially in the feasibility design of the process can be mostly economical because, planning costs should be kept as low as possible. Noted that, prediction of noise level in industrial processes helps to evaluate the pre- and post–prevention measures in terms of cost-benefit and efficacy. In addition, industrial health professionals can use noise prediction tools to calculate noise exposure level in any part of workrooms. It is therefore, possible to compare this value with noise exposure limit in order to evaluate various solutions of noise control programs. A number of models have been developed for predicting the noise level in enclosed
workrooms, ranging from simple empirical models to some more complicated and laborious models such geometrical models.\textsuperscript{7,8}

Acoustic features influencing the noise propagation, due to the complexity of their nature can harden the development of noise prediction models.\textsuperscript{7} Comparison of simple room acoustic models applied to industrial workrooms showed that empirical models with high validity and applicability are rare.\textsuperscript{9,10} On the other hand, development of geometrical models is complicated and needs computer and acoustics expertise and time-consuming calculations so that they are frequently employed in special cases.

The classic model of noise prediction in closed workroom was proposed by Sabin titled diffuse field theory based on the assumption that the distribution of sound energy within the room is homogeneous, and that sound absorptions is uniformly distributed. Mainly due to its simplicity, Sabine’s equation is normally used even though the real situations of workrooms seldom comply with its preconditions. The literature indicated acousticians are not altogether satisfied with the existing equations, thus this issue is still open for finding solutions better fitted to noise control applications.\textsuperscript{10,11} One of the most important issues in this area is assigning more practical methods which can analyze the complex relationships among different features affecting noise level in enclosed workrooms.

Presently, artificial intelligence approach is assigned as an alternative statistical technique.\textsuperscript{12} This approach is recognized as a new method for accurately modelling various sciences. The most important techniques of artificial intelligence are artificial neural networks (ANNs), genetic algorithm and fuzzy set. During the last decades; fuzzy set and neural networks have offered an interesting opportunity for analyzing the non-linear and vague information located in the complex phenomena of the actual world.\textsuperscript{13} ANNs can learn the knowledge of data via the process of empirical data.\textsuperscript{14} Hence, neural networks can be a good choice to study such physical phenomena as noise in which adequately data related to different features are being collected while the mechanisms of interaction effects cannot be fully inferred.\textsuperscript{15} Note that, in the field of architectural acoustics, neural networks have been used to predict the sound speech level in the classrooms and noise level in opencast mine.\textsuperscript{16,17} It was specifically developed to mathematically present uncertainty and vagueness and makes formalized implements for dealing with the imprecision intrinsic to many different real situations.\textsuperscript{18,19} The results of applying fuzzy logic to the development of noise control model suggest that the fuzzy logic can be utilized for analyzing very complex processes and be successfully applied to highly nonlinear systems.\textsuperscript{20,21} Both neural networks and fuzzy logic are principal techniques that have their strengths and defects. In order to have two abilities of learning and interpretability in a unique system, integrating neural networks and fuzzy systems, and forming adaptive neuro-fuzzy inference system (ANFIS), have been suggested.\textsuperscript{22,23}

In this regards, ANFIS can also be considered as a practical choice to facilitate development of the noise prediction model which makes highly accurate analysis of workrooms acoustics’ conditions possible. Considering the growing interest in developing noise prediction models with high level of validity and applicability, applying artificial intelligence methods can be very helpful and efficient. The noisy process of industrial embroidery is considered to be an important part of textile industry in which patterns and designs are imprinted on cloth.\textsuperscript{24} In this study, the application of such artificial intelligence approaches as ANNs, generate fuzzy inference system (GENFIS), and ANFIS in developing a noise prediction model in terms of real situation of the industrial embroidery workrooms was investigated.
2. Methods

In this study, the development of noise prediction models included different phases. The first phase consisted of selecting the appropriate research field in terms of noise pollution, recognizing likely features affecting the noise level of an industrial process, collecting and analyzing data set related to features. The second phase consisted of determining types and parameters of different structure of artificial intelligence methods. The third phase included separating the data in order to train and test data set and developing noise prediction techniques. Finally, the validity of the best developed models was assessed in terms of performance criteria using test data set. The data were collected from 60 industrial embroidery workrooms in the Khorasan province, East of Iran. Due to the nature of embroidery operations, the operators must be exposed to excessive noise with some risks of hearing loss. The main acoustical features were determined based on ISO 11690-3. The most important structural characteristics of workrooms were dimensions included length (L), width (W), height (H), total surface area(S), volume (v) and geometrical shape. Because the geometrical shapes of all workrooms were similar (all rectangular), this parameters was not considered as a candidate feature. The structural materials of workrooms were recorded carefully and their sound absorption coefficient values were specified from valid resources.26

The total equivalent sound absorption area of workrooms in m² units was calculated based on ISO 12354-6 standard. The equivalent absorption area in regular shape room was determined as follow.25

Equivalent absorption surface area of objects located in workrooms mostly included embroidery machines surfaces was also approximately estimated based on ISO 12354-6 recommendations 25. Average absorption coefficient of workroom (α) and room absorption constant(R) in m² units and reverberation time (RT) in second as important acoustic features were determined based on Sabin's theory.26

The type of machinery maker (MT), number of embroideries (NE), number of embroidery heads (NH), lifetime of embroidery machine (EL) and operation speed of embroidery (ES) were features of embroidery machinery which were recognized to be significant regarding noise emission. Further, most important feature of used raw materials, which could affect the noise level of embroidery operations, was the type of fabric (FT). The varieties of fabrics used were recorded in terms of thickness decreasing in seven major classes, including three layered fabric, felted, duplex cotton, lee, manoplex cotton, satin and silk, based on the ordinal scale.

Noise level in the workrooms under study was considered as a target feature in the prediction techniques. Measuring equivalent noise level (Leq) in workstations was performed based on ISO 9612 using integrated sound level meter Norsonic type 132.27 Regarding the length dimension of the machinery, three measurement points were considered as grid area in similar dimensions around the machinery. Then, logarithmic average of noise levels in reference points was calculated and recorded. Despite the uniformity of structural and acoustical features of each workroom, some new observations appeared in the workrooms by varying features of embroidery process and re-measuring noise level. Hence, the number of possibility recorded observations became 100.

To process and select the final features of noise prediction technique, statistical methods such as a correlation matrix were employed. Finally, nine features were recognized as final input features to develop the noise prediction technique. Descriptive statistics of the final structural, acoustical and embroidery processes features in the workrooms were listed in Table1.
Table 1. Descriptive statistics of final features of embroidery workrooms for developing noise prediction techniques.

<table>
<thead>
<tr>
<th>Features type</th>
<th>Symbol</th>
<th>Unit</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Workroom acoustic features</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average absorption coefficient</td>
<td>α</td>
<td>-</td>
<td>0.04</td>
<td>0.14</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>Room absorption constant</td>
<td>R</td>
<td>m²</td>
<td>4.10</td>
<td>26.09</td>
<td>12.25</td>
<td>6.11</td>
</tr>
<tr>
<td>Reverberation time</td>
<td>RT</td>
<td>s</td>
<td>0.94</td>
<td>4.21</td>
<td>2.70</td>
<td>0.89</td>
</tr>
<tr>
<td><strong>Embroidery process features</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of embroideries</td>
<td>NE</td>
<td>-</td>
<td>1</td>
<td>4</td>
<td>1.24</td>
<td>0.53</td>
</tr>
<tr>
<td>Number of embroidery heads</td>
<td>NH</td>
<td>-</td>
<td>6</td>
<td>40</td>
<td>14.31</td>
<td>5.70</td>
</tr>
<tr>
<td>Embroidery lifetime</td>
<td>EL</td>
<td>Year</td>
<td>1</td>
<td>20</td>
<td>11.40</td>
<td>5.34</td>
</tr>
<tr>
<td>Embroidery speed</td>
<td>ES</td>
<td>Stitches/Min</td>
<td>690</td>
<td>850</td>
<td>747</td>
<td>39.24</td>
</tr>
<tr>
<td>Fabric type a</td>
<td>FT</td>
<td>-</td>
<td>1</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Machine maker type b</td>
<td>MT</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Target feature</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise level</td>
<td>L_{eq}</td>
<td>dB</td>
<td>79.40</td>
<td>88.70</td>
<td>85.20</td>
<td>1.96</td>
</tr>
</tbody>
</table>

a This feature was based on ordinal scale.
b This features were based on nominal scale.

2.1. Neural Networks Structure

Multilayer perceptron, as used in this study, can be considered as the most widely accepted structure of neural networks, applied to physical phenomena. In terms of interconnections of neural networks structure, feed forward networks were considered. Training artificial neural networks was performed based on the supervised learning method using error back propagation learning algorithm. In this study, 80% of data set was randomly assigned to the training of the networks and 20% to the test of the networks. Training the networks continued until the number of certain epoch (100) is passed or the error variations of network prediction in a mentioned epoch are minimized. Each input feature was normalized by subtracting it from its mean value and then dividing the result by its standard deviation to have zero mean value and unity variance for all variables. In this study, neural networks have at least one hidden layer with the number of neurons being approximately between half and twice the number of input features (4 and 17). The networks were developed in MATLAB software. Genetic algorithm (GA) was employed to recognize the optimal values for initial weights of neural networks.

2.2. Advanced Fuzzy Systems Structure

One of the most widely used advanced fuzzy systems for modelling complex phenomena with various features is GENFIS. This method generates a sugeno-type FIS structure using subtractive clustering and requires separate sets of input and output data as input arguments. Due to the fact that there was not any clear thought about how many clusters could be exist in the dataset, so subtractive clustering, that is a fast algorithm for estimating the total of clusters and the cluster centers in the data set, was employed. After this step, the clusters’ information was applied for determining the initial number of rules and antecedent membership function used for constructing the fuzzy inference system (FIS). The initial FIS was generated using the MATLAB fuzzy logic toolbox func-
tion GENFIS \(^{30}\). In this study, a hybrid approach which combines the advantages of the FIS and the GA in the unique system in order to achieve a highly accurate noise prediction model was employed \(^{31}\). In this phase of study, GA was also employed to select the best GENFIS in terms of different parameters’ radius value for each input feature. Fitness function of the GA is constructed by minimizing the value of error prediction based on check data set by GENFIS. For this reason, 80% of data set was randomly selected and used to train networks and 20% to test the FIS equally.

ANFIS is a prevailing tool in fuzzy modelling was applied to generate the best FIS system. ANFIS utilizes the result from GENFIS to begin optimization and uses a combined learning algorithm to enhance parameters of sugeno-type fuzzy inference systems. It assigns a combination of the least-squares method and the back propagation gradient descent method for training FIS membership function parameters to copy a given training data set \(^{32}\). Root mean square error (RMSE) and coefficient of determination (R\(^2\)) are the commonly-used criteria for evaluating the performance of the prediction technique. These criteria determine the differences between predicted values and actual values of the issue.

### 3. Results

Empirical techniques for prediction of noise in industrial embroidery workrooms were developed using artificial intelligence approaches. Based on findings, neural networks structure with one hidden layer and 14 neurons exhibited the highest level of accuracy. Performance of ANNs in the train and the test phases based on RMSE and R\(^2\) was illustrated in Table 2. The performance of the developed advanced fuzzy inference system in form of GENFIS and ANFIS in terms of RMSE and R\(^2\) were also presented in Table 2.

<table>
<thead>
<tr>
<th>Model developing phase</th>
<th>Train</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMSE (dB)</td>
<td>R(^2)</td>
</tr>
<tr>
<td>ANNs</td>
<td>0.67</td>
<td>0.90</td>
</tr>
<tr>
<td>GENFIS</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>ANFIS</td>
<td>0.017</td>
<td>0.99</td>
</tr>
</tbody>
</table>

The results showed that prediction error of different structures of advanced fuzzy models were approximately similar. However, ANFIS could slightly improve the accuracy of noise prediction compared with GENFIS. It is noted that, accuracy of FIS techniques was also slightly higher than ANN prediction technique. Due to performance nature of FIS model, prediction errors in the train phase of the developed FIS techniques were significantly low. The scatter plots of measured values of noise level versus predicted values ANFIS were presented in Figure 1.

The main purpose for developing prediction model using artificial intelligence was application of this model for analyzing new cases of embroidery workrooms. The results showed that the developed empirical techniques can predict the effectiveness of the different noise control interventions on the noise level of embroidery workrooms. Naturally, acoustics analysis of the typical embroidery workrooms based on the developed techniques can facilitate using the graphical user interface (GUI).
4. Discussion

Highly accurate noise prediction techniques are considered to be an important tool for evaluating cost-effective noise control measures in industrial workrooms. Empirical techniques are more practical and quicker methods than other mentioned approaches for acoustic and occupational health experts. Artificial intelligence models are simple to apply and have generated a great deal of interest in engineering. By considering the successfully application of this approach in complex engineering problems, in this study, artificial intelligence methods were employed as alternative approach in the field of acoustics’ modelling to predict the noise level in closed workrooms which can be regarded as a complex phenomenon. The analysis of results showed that different prediction techniques could accurately predict the noise level in terms of acoustical parameters of workrooms and technical characteristics of real noise sources (embroidery machines). The prediction error of noise by the developed ANNs and GENFIS and ANFIS prediction models were lower than the subjective difference threshold for sound pressure level ±1dB mentioned in ISO 3382. The prediction error rate of developed techniques was at an acceptable level compared with similar studies that used artificial intelligence to predict the sound level in architectural and environmental acoustics’ areas.

The results confirmed the high capabilities of artificial intelligence approaches in improving the performance of acoustics prediction techniques compared with those of current empirical techniques developed using classical methods such as regression techniques in typical workrooms. Therefore, the developed empirical techniques can suitably predict the effectiveness of different scenarios (various solutions for noise control) on the noise level of embroidery workrooms. It was found that one of the main causes of achieving this highly accurate prediction technique was the application of genetic algorithm as a complementary method which can determine the optimal structure of ANN and FIS models.

The traditional method for constructing FIS is based on human’s capabilities and expert knowledge. Therefore, this approach cannot be useful if the phenomenon is very complex as is the case in noise pollution of enclosed workroom. ANFIS prediction technique had minimum prediction error compared with other developed methods. This result can be due to the best learning performance of ANFIS. In addition, comfort of implementation, speed and accuracy of learning, robustness of generalization capabilities, superior interpretation facilities through fuzzy rules and ease of incorporation of both linguistic and numeric knowledge for problem solving are other advantages of ANFIS method. Finally, the results confirmed the high capabilities of artificial intelligence ap-
proaches in improving the performance of noise prediction techniques compared with those of current empirical techniques developed using classical methods such as multiple regression techniques. It is noted that, the codes of the programs written in this research can be reached through the author’s email for public.

5. Conclusions

Workroom acoustic treatments can be very costly and subject to different limitations especially in the utilization phase. Prediction of noise level is crucial when analyzing different acoustic measures so that, more acceptable acoustic situations can be finally obtained. The accuracies of artificial intelligence models for predicting the noise in industrial embroidery workrooms were within the acceptable level according to the international acoustics standard. It was demonstrated that artificial intelligence techniques can be used for constructing accurate models to predict noise in enclosed workrooms as complex system and therefore, regarded as a good tool for minimizing the uncertainties in the field of industrial acoustic modelling compared with the traditional methods. The developed prediction models can be regarded as useful tools for occupational health and acoustics professionals in order to design, implement and evaluate various noise control measures in the noisy embroidery workrooms.

REFERENCES