Predicting the Fit between the Respirator and Face based on Facial Anthropometric Dimensions Using Neural-fuzzy Method (Used in Crises)

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Abstract

Background: The occurrence of crises such as the outbreak of the new coronavirus (COVID-19) showed that the availability of a mask that fits the face is of great importance for individuals. The present study was performed to design a tool to assess the facial fitness of the mask based on face dimensions.

Methods: A hybrid method is introduced which consists of modeling of a fuzzy system using a neural network, so that with only one-time training of this neuro-fuzzy system, ANFIS, it is possible to easily determine the fit of N95 respiratory mask only by applying the anthropometric dimensions of the face. Six anthropometric dimensions of the face were assigned as the inputs and respiratory mask fitness was assigned as the output of the ANFIS model.

Results: The proposed neuro-fuzzy system, ANFIS, is designed in such a way that by specifying the input parameters for each individual, the fitness of the mask to the face can be predicted.

Conclusion: According to the results of the probability predicted by the neuro-fuzzy system, using the data of the six dimensions of the face, in about 75 percent of the cases the fitness of the mask to the face of individuals can be predicted accurately; therefore, the designed ANFIS network can be used instead of the fitness test to predict the fitness of the respiratory mask to the face using the anthropometric data of the face of the individuals only when it is not possible to perform the fit testing.

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Introduction

Whenever the applied engineering and management controls to remove environmental pollutants from the respiratory tract are not at an acceptable quality level, the last and easiest procedure of respiratory protection is using respirators.[1] N95 Half Facepiece Respirators are the most commonly used respirators in industries and healthcare systems.[2] Although these respirators are envisaged to prevent the penetration of at least ninety-five percent of particles ≥0.3µ, in practice, this usually does not work. Sun points out that the efficiency of respirators' electret can be more than 95%.[3] However, this study just deals with filter efficiency and impermeability, and the Human Factors (HF) for respirators are neglected. Most citizens use masks that are designed to prevent the penetration of contaminants, but they do not fit their face and are too loose for them; therefore, they do not provide adequate protection against contaminants. In fact, the effectiveness of commonly used masks is less than 50%.[4] There are various qualitative and quantitative fit test procedures to ensure that the mask is fit to the face.[5] However, special facilities are required to use these tests. The occurrence of crises such as the outbreak of the new coronavirus (COVID-19) due to SARS-COV-2 infection, which appeared in China in late December

2019 (Chinese article), revealed the significance of the mask that fits the face;[6-8] this issue was considered as a social concern, even in China, the largest producer of masks in the world.[9] In fact, using fit tests is impossible for all people in such critical situations, and the need for other tools to determine the fitness of the mask with the face was felt.

In their study, Huailiang Wu et al. concluded that in crises such as the outbreak of the new coronavirus (COVID-19), global production (even the full production of 20 million masks per day) does not meet the needs of $1-4 billion Chinese population.[9] However, an important point that is often overlooked during the crisis is the reduction of the respirators' effectiveness if it does not fit the face. Many people do not pay attention to the fitness of the respirators with their faces while using them and think that they are more effective in protecting the respiratory system than it really is, and this lack of awareness can be dangerous.[10-12]

Various studies have emphasized that the contour of the respirators is better to be tightened with the face based on the users' facial anthropometric dimensions data.[13] Many studies have concluded that the respirator's leakage is closely related to the design of its size in proportion to the face dimensions.[14, 15] The issue of respirators being fit with the user's face depends on many factors and is often due to the shape and inequalities of the face; the leakage of the respirators is highly affected by the degree of tightening the mask in the nose and chin areas. Some studies have emphasized that tightening the face with the contour of the respirators is an important variable in the amount of leakage.[16]

It should also be noted that different countries should have their own population data. The Chinese have shorter face lengths, shorter nasal protrusion, wider face widths, and longer lips than Americans, and several studies have emphasized that the produced N95 respirators should be improved based on the Chinese face dimensions.[17] Although many ergonomic studies have been performed on the face, to design and make the respirators fit in the world, there are few studies on the Iranian population. Various studies have suggested that different dimensions of the face are involved in tightening the respirators on the face. In most of them, the length and width of the face have been considered as the most important dimensions.[17] In the study carried out by Idris et al., four dimensions of the face length, face width, nose width, and lips width have been mentioned as effective dimensions on the respirators' fitness to the face.[17] After examining the effect of twelve dimensions of the face with statistical tests on the fitness of respirators on the face, Zhuang et al. concluded that there was more relationship between six dimensions of face length, face width, lips width, nose width, nasal protrusion, and biogonial width and the degree of respirator's fitness on the face.[18] The important point was that various statistical tests were used in all these studies to examine this relationship and the results of the respirators fit test, but, so far, the relationship between the dimensions of the face and the respirators fitness has not been examined by the fuzzy-neural method. The hybrid fuzzy-neural method is a statistical model that has recently attracted a lot of attention. Adaptive Neuro-Fuzzy Inference Systems (ANFIS) result from the integration of fuzzy structures with artificial neural networks, which are used to identify the systems, predict time series, and a variety of other cases. Simulation of nonlinear systems, high accuracy, and less time of making the model and its calculations are among the advantages of this model. In this study, we decided to examine the relationship between facial anthropometric dimensions (Table 1), including the face length, face width, lips width, nose width, nasal protrusion and biogonial width (which have the greatest effect on tightening the respirators on the face), and the results of the N95 Respirator Fit Test on the face of health care staff using fuzzy-neural network modeling. Our hypothesis was that if this modeling is done along with the considerable error, introducing this model can be useful to predict whether or not the respirator is fit on the face using the face dimensions because performing the fitness test for the staff requires sufficient budget, time and hiring skilled people in this field.

Therefore, creating a model based on the collected data from the Iranian population can be useful to predict the degree of the fitness of the respirator for Iranian health care staff, in the event of crises such as outbreaks.

Methods

This study was conducted using the results of a study performed by Jazani et al. (2016),[10] and measurement of anthropometric dimensions and respirator fit test

Table 1: Definitions of anthropometric dimensions of the face

Abbreviation	Definitions
Mensellh	Straight-line distance between the menton landmark and the sellion landmark at the deepest point of the nasal root depression
Bizbdth	Maximum horizontal breadth of the face between the zygomatic arches
Liplgthh	Straight-line distance between the right and left cheilion landmarks at the corners of the mouth
Nosebrth	Straight-line distance between right and left alare landmarks on the sides of the nostrils
Noseprh	Straight-line distance between the pronasal landmark on the tip of the nose and the subnasal landmark under the nose
Bigbrh	Straight-line distance between the right and left gonion landmarks at the corners of the jaw

of the health care staff, on 403 personnel of Masih Daneshvari Hospital (Pulmonary Diseases Hospital) and Mofid Hospital in Tehran. The study included 272 women and 131 men, aged 20 and 60 years old, with the median age of 32. In this study, six facial dimensions with a close relationship with the function of respiratory masks[19, 20] and all facial anthropometric dimensions in millimeters with two decimal places, using sliding and pulling calipers, were measured. A qualitative fit test was done on the participants of this study using saccharin, as a test agent, and in accordance with the instructions of the Occupational Safety and Health Administration (OSHA). The JSP 832 FFP3 respirator was used for all of them that is one size. Although this respirator is N99 and provides higher protection than the N95, its one-size-fits-all is very important, as this study showed a low rate of fit.

The Proposed Method Using Fuzzy-Neural

In this paper, a hybrid method is introduced which consists of modeling of a fuzzy system using a neural network, so that by training this fuzzy-neural system, ANFIS, determining the fitness of N95 respirator is easily possible just by applying the facial anthropometric dimensions.

Fuzzy-neural systems can be implemented in two forms. In the first one, fuzzy operations or fuzzy numbers can be used in neural networks. In the second form used in this paper, the fuzzy system can be performed neutrally.[21] In other words, using input and information, the fuzzy system can be designed by the neural network to adapt its membership function (MF) input and output functions, and fuzzy rule base to this information. The proposed fuzzy-neural method, as shown in Figure 1, can be expressed as a multilayer network, so that its first layer is the input layer and a coefficient is used to map the input quantities at intervals [1-0]. In this paper, the input number of the fuzzy-nervous system was equal to the number of studied subjects, and six facial anthropometric dimensions were used. The second layer is the fuzzification layer, which calculates the number of inputs belonging to the input fuzzy sets using the input membership function. The third layer is the fuzzy inference decision layer. In this layer,

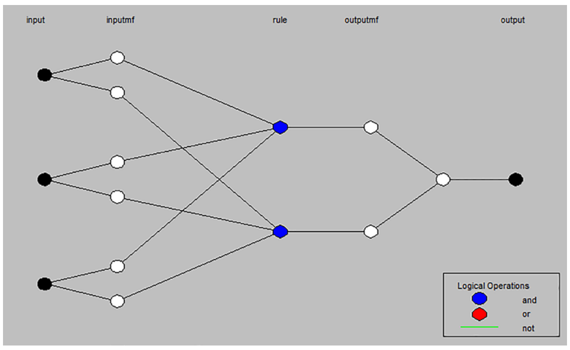

Figure 1: ANFIS arrays with two input membership functions

there is a law considering the number of fuzzy sets. In the fourth layer, the defuzzification layer, there is a sequence of control rules, and the defuzzification operation is performed simultaneously. Also, there is a neuron corresponding to each controller output. The network output is the fitness of the respirator to each person's face.

ANFIS in MATLAB software was used to model a fuzzy system using a neural network. The hybrid method, which is a combination of the Least-Square method and the Backpropagation method, is used to train the ANFIS structure, and the applied Fuzzy Inference Systems is a Sugeno type fuzzy system. To optimize the model, we used different types and numbers of membership functions to determine the optimal number and type. Six facial anthropometric dimensions, including face length, face width, lips width, nose width, nasal protrusion, and biogonial width, were identified as the input of ANFIS, and the respirator fit was specified as its output. In order to normalize the input data and map the input quantities at intervals[1-0], we used the sigmoid function in the ANFIS network according to the following Equation (1).[21]

$$X(k)_i = \frac{X(k) - \min(X(k))}{\max(X(k)) - \min(X(k))}$$

Where is the components of the input vector. The mean squared error (MSE) and correlation coefficient (R^2) were used to control the training process; their calculation method is shown in Equations (2) and (3), respectively:

$$MSE = \frac{1}{N}\sum_{i=1}^{N}\left(x_f - x_t\right)^2$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(x_f - x_t\right)^2}{\sum_{i=1}^{N}\left(x_f - \bar{x}\right)^2}$$

Where is the fitness of predicted respirator by the ANFIS network, is practical test results of the respirator fitness with the face of health care staffs, and Is the laboratory average values.

Results

Approximately, 70% of the data in this study were used to design and tune the network, and the rest to network validation and test, so that characteristics of 300 people have been used to train the fuzzy-neural network, and respirator fitness with their face was determined by the qualitative fit test using saccharin. Then, to validate the ANFIS network, we calculated the probability of the mask fitness to the remaining 100, the results of which are shown in Step Figure 2.

Figure 2 shows the success or failure of the fit

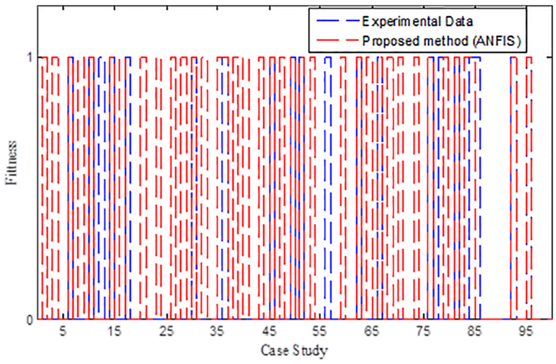

Figure 2: Success or failure in the fit test (comparing the results of the fit test and those of the model)

test of the respirator and face in 100 subjects, using the actual results of the fit test and the fuzzy-neural method. According to the results, the predicted probability by the fuzzy-neural system has a 25% error compared to the values obtained from the fit test. Comparing the results of ANFIS network results and actual results of the fit test shows the accuracy of the trained system.

Discussion

According to the results of the predicted probability by the fuzzy- neural system, using data on the six dimensions of the face length, face width, lips width, nose width, nasal protrusion, and biogonial width, about 75% of cases can correctly predict the respirator fit on the faces; therefore, the designed ANFIS network can be used to predict the respirator fit with the faces by using the facial anthropometric data instead of the fit test, while fit testing is not possible, like when there is a need to store respirators for critical situations. Of course, by increasing the number of subjects or measuring more dimensions of the faces, modeling with ANFIS is also possible with fewer errors.

Given that the majority of the staff use respirators that do not provide the necessary protection for them, and this can reduce the protection level of the staff who are exposed to the pathogens and reduce their level of health; moreover, it leads to problems in the infection control system of the hospital, and also indirectly increases the costs and reduces the productivity. In 2014, a study examined the effect of the respirator fit rate on reducing the risk of infection (M.tb). The results showed that the fit rate of 95% reduced the infection rate by 95%, and the fit rate of less than 8% reduced the infection rate by 70%.[22]

Fit test, in addition to the need to various devices such as a hood, nebulizer, and saccharin solution, requires a specialist to perform the test. Although performing this test is a better way to check the fit of the respirator with the face, using the proposed model in this study can also be used as a simpler solution, especially during the crisis when available facilities are not available.

In this paper, a new hybrid method is proposed to examine the respirator fit to faces using modeling fuzzy system by a neural network. The proposed fuzzy-neural system, ANFI, is trained to predict the respirator fit to the face by specifying the input parameters for each individual. ANFIS input parameters, face length, face width, lips width, nose width, nose protrusion, and biogonial width were selected, which have the greatest impact on the respirator fit to the face.

The characteristic of the ANFIS network is that the parameters included in its designing were fewer than the neural network; as a result, its training is easier than the neural network.

Conclusion

Comparing the results of the present article showed that the proposed method, in comparison with the qualitative fit test method, at least in some cases, where the fit test is not possible, has considerable accuracy and its efficiency and simplicity are obvious at least to design, purchase and store the respirators in the crisis. However, due to the limitations of the available data to conduct this study, the probability of error is relatively high, and it is recommended that, to enhance accuracy, data should be collected in which qualitative fit test results are obtained for the staff, and before taking the test, they should be trained on how to use respirators correctly to be trained them. If this modeling is done for data with the mentioned features, the results will be much more accurate.

Conflict of Interest: None declared.

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