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AN ARTIFICIAL NEURAL NETWORK MODEL FOR PREDICTING FATIGUE OF CONSTRUCTION WORKERS IN HUMID ENVIRONMENTS

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Climate change is experienced in many countries located in tropical/ subtropical regions with generally hot/humid condition. Heat illness, particularly heat stroke, has caused a substantial increase in morbidity and mortality during heat waves. Thus, the high incidence of heat stroke is a pressing concern in the construction industry. Construction workers, being exposed to such unpleasant working environment, are at a higher risk of heat stress while undertaking physically demanding tasks. This paper aims to establish a model for predicting fatigue of construction workers in hot weather. During the period of summer months in 2010 and 2011, we conducted 39 field measurements on six construction sites in Hong Kong and collected a series of meteorological, personal, and work-related parameters. A total of 550 synchronized datasets were measured to establish the model. Artificial neural networks (ANNs), a type of artificial intelligence technology which implements more complex data-analysis features into existing applications, was applied to forecast the fatigue of construction workers. Performance measures including mean absolute percentage error (MAPE), R^2, and root-mean-square deviation (RMSE) confirm that the established model is a good fitting with high accuracy. The ANN-based model presents a reliable and scientific forecast physical condition of workers which may enhance the occupational health and safety (OHS) in the construction industry.

Keywords: Back propagation neural networks (BPNN), Construction industry, Heat stress, Multiple linear regression (MLR), Occupational health and safety (OHS), Rebar worker.

1 INTRODUCTION

The construction industry is recognized as one of the most dangerous industries that at least 60,000 fatal accidents occur each year on site around the world (International Labour Organization 2005). Aside from the dangers of being the front-liners on a jobsite, workers in the construction industry also confront potential hazards (e.g., temperature extremes, radiation, chemicals, dusts, vibration, and noise) and suffer impaired heath illnesses. Approximately 30% of construction workers in some European countries suffer from pain and musculoskeletal disorders (European Agency for Safety and Health at Work 2010). In Hong Kong, it was found that 56.0% of construction workers are overweight based on the BMI classification and 19.5% of them have active pain symptoms (Chan *et al.* 2015). During these years, academics in the construction industry made their efforts on the safety problems and less attention has been taken to occupational health issues. Nevertheless, occupational diseases and injuries in the construction workers lead to low productivity, physical disability and even death (Boschman *et al.* 2010).

Heat stress is a severe occupational hazard that should be contemplated on construction sites during summer time. Workers in the construction industry are susceptible to heat stress not only because of the exposure to solar radiation, high temperature, and high humidity but also the high intensity of physically demanding tasks (Tiwari and Gite, 2006). Environmental heat load combined with physical work result in impairment of mental function and increased fatigue (Christensen *et al.* 2000). Fatigue is defined as a reduction in physical and mental work capacity (Lawson *et al.* 1999). Previous studies demonstrated that fatigue is associated with the age, physique, percentage of body fat, smoking, alcohol consumption (Lallukka *et al.* 2004, Cavuoto and Nussbaum 2013). Under sustained or increasing stress, fatigue may lead to impaired work performance, injuries, and accidents. These symptoms indicate that construction workers are suffering escalating strain in response to stress. Stress is defined as the physical, mental, or environmental load imposed on human (Budd *et al.* 1997). Common sources of stress on the construction site include the intensity of task, work duration, extreme temperature (Versura *et al.* 1999, Christensen *et al.* 2000). The strain experienced by construction workers can include physiological responses and subjective responses such as increases in perceived exertion and thermal discomfort (Ammari *et al.* 2009).

Earlier studies by Chan *et al.* (2012) were conducted to construct a multiple linear model (MLR) to predict perceptual response of construction workers in hot environments. Although one of the most widely used technique for analyzing multi-factor data, MLR is generally limited by the linear relationship between dependent and independent variables (Jahandideh *et al.* 2009). Thus, more advanced analytical techniques are required to tackle these complex issues. Artificial neural networks (ANN), a form of artificial intelligence technique, have been proved to be a suitable and useful statistical technique for solving with a complex problem and developing high predictive model (Atanassova and Dimitrov 2011). This study aims to develop a model to predict a worker's fatigue in hot and humid environment by the application of ANN.

2 MATERIAL AND METHODS

2.1 Database

The research team conducted field studies on six construction sites in Hong Kong between July and September in 2010-2011, to collect necessary dataset. Thirty-nine experienced and healthy construction rebar workers participated in the field measurements. A total of 550 sets of environmental, personal, and work-related data together with the corresponding perceptual responses were used in this study as dataset.

2.1.1 *Fatigue*

The rating of perceived exertion (RPE) was adopted to quantify the fatigue of the construction worker. RPE was developed for a person to subjectively report their perception of fatigue and physical effort. Several studies have used RPE as an indicator to monitor exercise tolerance (e.g., Foster *et al.* 2001). A ten-point single-item RPE scale with the ratings between 0 (nothing at all) and 10 (extremely hard) was used to assess workers' perceptual responses.

2.1.2 *Environmental data*

Wet-bulb globe temperature (WBGT), a widely used and reliable heat stress index, was adopted to measure the meteorological condition of the construction site. It is a comprehensive thermal index that involves air temperature, humidity, wind velocity, and solar radiation (Budd, 2008). A heat stress monitor was set aside the participants to monitor WBGT for every minute.

2.1.3 *Personal data*

Demographic details including age, weight, height, smoking habit, and alcohol drinking habit were requested prior to the test. The smoking habit was classified into "no consumption", "1-4 cigarettes per day", "more than 5 cigarettes per day". The alcohol drinking habit was categorized into "no consumption", "no more than 4 prescribed quantity on any single day AND 14 prescribed quantity per week", and "More than 4 prescribed quantity on any single day OR 14 prescribed quantity per week" according to the National Institute on Alcohol Abuse and Alcoholism (NIAAA) (2010).

2.1.4 *Work-related data*

The duration of the operation and the work of the workers were tracked by a timer. Workers of different trades may be subject to different degrees of physical demands. The nature of jobs (bar bending and bar fixing) is therefore included as another variable that affects the RPE of workers.

2.2 BPNN

The backpropagation neural network (BPNN) is the most classically and generally used training algorithm in ANN approaches (Örkcü and Bal 2011). BPNN is feed-forward neural network with multi-layer perceptrons that is trained by the error backpropagation (BP) algorithms. A three-layered BPNN model was developed to establish the relationship between RPE and factors affecting workers' fatigue in hot environments. Therefore, the BPNN model contained seven input neurons (i.e., WBGT, age, PBF, alcohol-drinking habit, smoking habit, work duration, job nature) and one output neuron (RPE). In terms of the sum-of-squares error (MSE), the best performance of the BPNN model was obtained for the configuration characterized by 12 neurons in the hidden layer. Therefore, the 7-12-1 neuron configuration was determined as the optimal network architecture.

2.3 Performance Evaluation

Correlation coefficient (R^2), mean absolute percentage error (MAPE), and root-mean-square deviation (RMSE) were used to evaluate the performance of the ANN prediction model. The higher R^2 values indicate greater similarities between the measured and predicted values, and the lower MAPE and RMSE values represent more accurate prediction results. The R^2, and MAPE, RMSE values were calculated using Eq. (1)–(3), respectively.

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(t_i - s_i)^2}{\sum_{i=1}^{N}(t_i - \overline{s})^2} \tag{1}$$

$$MAPE = \frac{1}{N}\left(\sum_{i=1}^{N}\left|\frac{t_i - s_i}{t_i}\right|\right) * 100 \tag{2}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(t_i - s_i)^2} \tag{3}$$

where t_i is the measured (experimental) values, s_i is the predicted values, N is the total number of data and $\overline{s}$ is the average of predicted values.

3 RESULTS

An ANN-based predictor model using Levenberg-Marquart BP was constructed for predicting workers' fatigue in hot and humid environments. This model was trained using 384 randomly selected samples; the remaining 166 samples were equally divided for the ANN validation and testing process. All performance measure values confirmed a good-fit and a robust model. As shown in Figure 1, the values obtained through the training, validation, and testing of ANN model are identical with measured data, implying the input parameters were strongly correlated with the output parameter. The R^2 value of 0.97 indicates the prediction performance of ANN model is accurate and reliable. It was also observed the prediction values obtained by ANN were determined with very low percentage errors (see Table 1). These levels of errors are satisfactory for predicting RPE.

Table 1. Performance criteria used for predicting RPE by the ANN and MLR models.

Data	Performance criteria		
	MAPE	RMSE	R^2
Training data	1.276	0.641	0.961
Validation data	2.365	1.063	0.895
Testing data	2.097	0.945	0.902

4 DISCUSSION

This result implies that the model designed is capable of explaining at least 89% of the measured data. These results indicated that the ANN model provided higher prediction results compared to the earlier model using MLR. The R^2 value of the earlier MLR model is 0.78 (2012). However, MLR distinguished work duration, alcohol drinking habit, and age as more significant parameters. ANN is beneficial in situations where influencing variables are not fully understood or controlled and/or numerous (Tiryaki and Aydin 2014). However, the black box nature of ANN limited the model to give appropriate interpretations of the estimated relationship. Since the aim of this study was to predict workers' perceptual responses, the predictive accuracy is of the most importance. Thus, the black box nature is not a shortcoming in such applications.

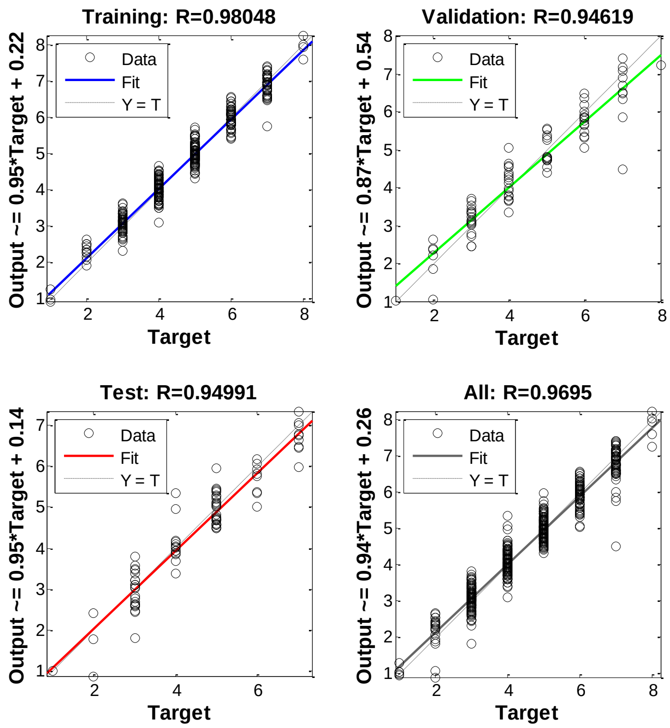

Figure 1. Relationship between the measured values and RPE values predicted by the ANN model for (A) training data, (B) validation data, (C) testing data, and (D) all data.

5 CONCLUSION

Construction workers are at a higher risk of being exposed to heat stress while undertaking physically demanding tasks. This study established an ANN-based model for predicting workers' fatigue in hot and humid environment. The current study illustrates how ANN technique can be applied in predicting heat strain of construction workers. It contributes to filling the research gap arising from limited studies in safety evaluation in hot and humid environments, an issue of rising importance.

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