Artificial Neural Network and Genetic Algorithm Optimization uses in Modeling Corrosion of Reinforced Concrete

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WeARE Research Area

My research is based on the application of machine learning, specifically a neural network trained using a genetic algorithm, to develop predictive models of corrosion in steel reinforced concrete. The model aims to predict carbonation depth in steel reinforced concrete based upon environmental conditions and the material characteristics of the concrete itself.

Background

The DURACON, ("Effect of the environment on reinforcement durability") Project, is a long-term collaborative research effort across 10 Ibero-American countries with the goal of determining environmental and material factors and their correlation on the performance of reinforced concrete structures. [1] Carbonation depth in reinforced concrete, material properties of the concrete, and local environmental conditions were measured across 24 test sites located in Argentina, Bolivia, Colombia, Chile, Costa Rica, Mexico, Portugal, Spain, Uruguay, and Venezuela. The material characteristics of the concrete included the capillary absorption and the concentration of Calcium Oxide within the concrete. "Capillary absorption represents the main mechanisms for water and water vapor transport in concrete." [2] The research performed over the fall semester aimed to create a trained neural network to predict carbonation depth based on the measured data from the Duracon Project. A neural network is, "an adaptive system that learns by using interconnected nodes or neurons in a layered structure that resembles a human brain." [3] The neural network was optimized using a genetic algorithm. Genetic Algorithms are, a method of solving optimization problems based upon the biological process of of natural selection. [4] The algorithm creates a series of solutions iteratively, borrowing concepts from biological evolution. For each generation of solutions, the strongest or most accurate solutions are chosen. Those traits, or aspects of the solution, are passed on to the next generation with some random mutations added in.

Objectives

The objective of this research was to combine the fitting capabilities of neural networks with the optimization abilities of genetic algorithms. These two processes were used to build a predictive model for carbonation depth in reinforced concrete. The genetic algorithm was used to optimize the values of the weight and biases of each neuron within the neural network.

Methodology

The data collected at urban stations throughout the first 8 years of exposure in the DURACON Project was used to train the neural network to predict carbonation depth. The predictive model used 6 input variables to predict the output variable, carbonation depth. Carbonation depth is the distance from the concrete surface in which carbon dioxide has reacted within the calcium in the concrete forming calcite ($CaCO_3$.) Carbonation depth was measured in the windward facing side of the reinforced concrete specimens. The input variables included both, the environmental conditions and the material properties of the concrete. The environmental conditions considered include the average values of temperature, relative humidity, and annual precipitation. The material characteristics of the concrete include capillary absorption and the calcium oxide content. The final input considered was the time at which the carbonation depth was measured.

The data was standardized prior to training using equation 1 below.

$$Z = \frac{x-\bar{x}}{\sigma} \quad (1)$$

Z represents the standardized data point. The original data point is represented as x. $\bar{x}$ represents the mean value of each variable. The standard deviation within each variable is represented as σ. Standardization helps to make the the training process more computationally efficient in training the neural network. [5] It was then used to train the neural network. The neural network uses a hidden layer with neurons to account for interactions between input variables and the output variable. The model used included 1 hidden layer containing 10 neurons. The neural network architecture can be seen in Figure 1.

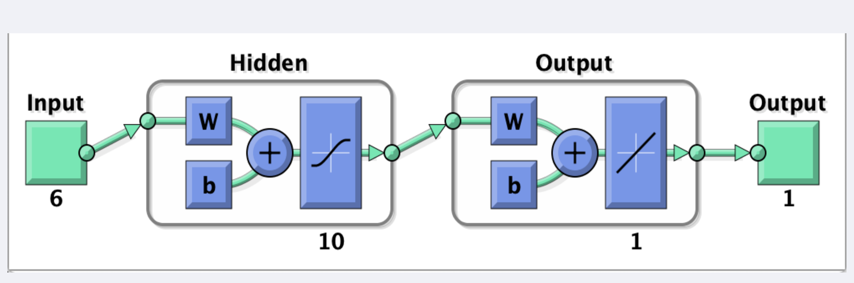

Fig. 1

Illustration of Neural Network

The standardized input and output, or target, data was then used to train the neural network using a genetic algorithm. The genetic algorithm sought to minimize the difference between the predicted value and the measured, or target, value.

Results

The genetic algorithm optimization of the weights and biases used in the neural network resulted in an accurate prediction of carbonation depth with the given inputs. The use of a genetic algorithm to train an artificial neural network was computationally expensive.

Model training was performed using MATLAB on a MacBook Pro with 8 GB of memory and a 2.7 GHz Dual-Core Intel Core i5 processor. The time required to train the neural network ranged between 200 second and 900 seconds. This large range in values can be attributed to the variances in initial guesses generated by the genetic algorithm. The genetic algorithm randomly generates an initial guess for the values of weights and biases of each neuron. Therefore, the computation time is highly dependent on the quality of each initial value generated. The accuracy of the resulting model can be seen in Figure 2 which shows the predicted values against measured, or target, values of carbonation depth for each input.

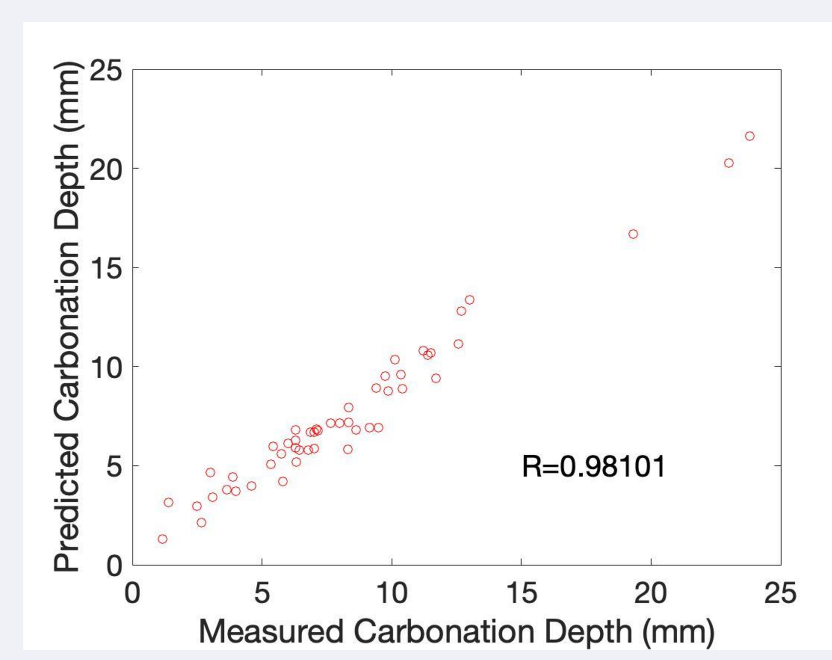

Fig. 2

Correlation between Predicted Values and Actual Values of Corrosion Depth

The model's predicted carbonation depth closely followed the measured corrosion depth for each sample. The coefficient of correlation (R) between actual and predicted values was found to be 0.98101. The results show a strong correlation between the input variables and carbonation depth. This level of correlation shows the capability of using a genetic algorithm to train a neural network.

Further testing and additional data is needed to ensure that the model is calibrated accurately and can be used to make more generalized predictions with new input data. Additional steps to improve upon the research presented are shown in the section below entitled, "Future Plans."

Skills and Experience

Prior to participating in this research, I have had the opportunity to gain experience in a variety of professional fields. I have worked in positions ranging from a subsurface utility engineer technician to working as the packaging engineer intern at a cosmetics company. I have previous experience with MATLAB and various modeling software, AutoCad and Solidworks, throughout my coursework at UTSA.

What I Learned

This research provided me the opportunity to learn much about how machine learning works, and the the steps needed to prepare data for input into a machine learning algorithm. I also was able to fully understand the mechanisms of corrosion. The research exposed me to the many possibilities of MATLAB in computational analysis.

Future Plans

The process outlined in this report is to be further optimized to ensure that the data is not susceptible to overfit. Once satisfactory progress has been made on the urban environment data, the work is to be continued in building a model to predict corrosion rate in marine environments. Methods used within this research can be applied to additional problems in which a predicted output is desired given any number of inputs. I plan to take a graduate level course in corrosion engineering to further my understanding of the mechanics of corrosion. I also plan to take a course within the school of data science focusing on programming to build upon my ability in data organization and visualization.

Acknowledgments

This work is supported by the USDA National Institute of Food and Agriculture, Interdisciplinary Hands-on Research Traineeship and Extension Experiential Learning in Bioenergy/Natural Resources/Economics/Rural project, U-GREAT (UnderGraduate Research, Education And Training) program (2016-67032-24984). I want to personally acknowledge the support and resources given to me by Dr. Brendy Rincon Troconis, Dr. Oladis Troconis de Rincón, & Dr. Arturo Montoya. I want to thank them for spending time with me each week to help me to better understand and improve upon the research done this past semester.

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