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Compressive Strength Prediction of High-Performance Hydraulic Concrete Using a Novel Neural Network Base d on the Memristor

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Abstract. This paper proposes the memristor-memristor (M-M) and the memristor-gradient descent (M-GD) neural networks based on the classical back propagation neural network. The presented models are employed to predict the compressive strength of high-performance hydraulic concrete (HPC), and are tested by well-fitting and accurate predictions with the experimental data. The developed algorithms are also evaluated through comparisons with the classical learning algorithms including the gradient descent method, the gradient descent with momentum, the gradient descent with adaptive learning rate, the elastic gradient descent, and the Levenberg-Marquardt algorithm. It is observed that the established M-GD generally outperforms the classical algorithms and M-M. The constructed M-M neural network has a quite high convergence speed, and the strength prediction error induced by it can roughly satisfy the demands in construction engineering. This work extends the nonlinear memristor to a brand-new field, and provides an effective methodology for forecasting the compressive strength prediction of HPC.

AMS subject classifications: 92B20, 65K05, 60G25

Key words: Artificial neural network, memristor, high-performance concrete, compressive strength.

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1 Introduction

As one of the most widely used building materials in modern engineering structures in the world, the concrete plays an important role in the building construction and civil en-

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gineering. Driven by the development of modern capital construction and new construction technology, the special demand of concrete performance in construction industry becomes critical. The high-performance concrete (HPC) [1–3] is a kind of construction material with many special properties which include high workability, high strength, high volume stability, and high durability [4]. The HPC has gained increasing popularity and been extensively studied over the last decade. It has potential to be used in a large number of huge projects [5] such as nuclear reactor, sea-crossing bridge, nuclear waste containers, and submarine tunnel.

Compressive strength is a critical mechanical property to measure the quality of HPC which is a hot topic in the HPC research recently. Compared with strength prediction of conventional concrete, evaluation of HPC strength is relatively difficult. Chou et al. [6] demonstrated that the compressive strength of HPC shows a highly non-linear relationship with each component of concrete, and so some characteristics of the HPC are not completely understood. This unfortunately leads to the inability of traditional predicting methods [7, 8], which are generally based on maturity concept [9, 10] of concrete or the value of fresh concrete test [11] to be used.

In the last decade, the artificial neural network (ANN) [12–15] has been extensively employed in determining the concrete strength due to its self-organization, self-adaptability, reasoning ability, and self-learning ability [16]. Kasperkiewicz et al. [17] stated that the ANN could be applied to forecast the compressive strength of HPC and it also shows promising potentials in optimizing concrete mixes. Nehdi et al. [18] illustrated that the ANN is able to accurately estimate the concrete slump, the segregation, and the filling capacity. It is also proved by Kim et al. [19] that the ANN is a powerful tool in forecasting the compressive strength of concrete based on the mix proportions. Furthermore, combined with other techniques, the neural network has been improved to some extent [20–22]. The results show that the neural network model has high accuracy and strong predictive ability, and its superiorities in the strength prediction of HPC with complex internal rules are more obvious.

Considering the complexity of the neural network itself, its weight needs to be constantly adjusted and updated. For the circuit implementation of neural networks, the circuit design of artificial neural network synapses has always been a thorny problem. The integrated circuits and ultra-large-scale integrated circuits have been tried to complete the design of artificial synapses. However, due to the complexity of circuits and traditional devices, its large size and high power consumption make it difficult for such artificial synaptic circuits to be highly integrated, and also make its density difficult to achieve the requirements of biological neural networks. Currently, transistors are used to construct hardware circuits of neural networks which are mainly for the simulation of neurons and synapses. However, this technical settlement derived from the Very Large Scale Integration Circuit is restricted by the huge number of transistors required for the simulation and its high power consumption. In addition, synaptic transmission characteristics are affected by time and space. Therefore, it is a tough work to construct the hardware circuit of the neural network with the existing components. Fortunately, the