스마트 팩토리에서의 HVAC 시스템 제어용 온도 예측 알고리즘 설계를 위한 인공 지능 적용

응오치히에우*, 딘민차우*, 응고만투안*, 다어반권**, 김창순**, 박민원*
국립창원대*, 빅아이**

Application of artificial intelligence to design a temperature prediction algorithm for controlling an HVAC system in a smart factory

Chi-Hieu Ngo*, Minh-Chau Dinh*, Manh-Tuan Ngo*, Van-Quan Dao**, Chang-Soon Kim** and Minwon Park*
Changwon National University*, BAI Corp**

Abstract - Predicting environmental temperature for factories and office buildings is the basis for controlling the ON/OFF of heating, ventilation, and air conditioning (HVAC) systems. This paper developed a temperature prediction model for a smart factory by long short-term memory and the recurrent neural network (LSTM-RNN) method. The data was collected and installed in layers of the LSTM-RNN algorithm to train the model. The LSTM-RNN's design factors were determined while training and testing the model. After testing the LSTM-RNN model, the results show that the accuracy of the model was about 98% with relatively small errors. The results of this study play a very important role and will be applied to control HVAC systems ON/OF in the smart factory.

1. Introduction

Recently, the energy demand has become a big problem in the world because of the rapid population growth and the development of the high-tech industry. Especially, with the explosion of industry 4.0, robotic systems and heating, ventilation, and air conditioning (HVAC) systems were applied to improve productivity and control ambient temperature in the factory. These systems use a lot of energy, for example, HVAC systems use about 30% of the total energy consumption in office buildings and up to 50% in more extreme climates [1], so the power consumption is increasing day by day in factories. This can break stability and disrupt production if the energy demand increases fast and sudden. Therefore, the factory energy management systems have been developed and applied to control the energy demand and ensure production activities. Environmental temperature prediction for controlling HVAC systems is one of the essential factors for managing and saving energy in factories. There are many methods to design temperature prediction models and artificial intelligence algorithms are being applied very popularly with high results due to the development of technology and big data. Long short-term memory and recurrent neural network (LSTM-RNN) is a special type of artificial neural network that is adapted to use sequential data or time-series data [2].

In this paper, the authors designed and developed a temperature prediction model for a smart factory by the LSTM-RNN method. The temperature prediction model was built on the temperature dataset that was measured and recorded by the company. The data was aggregated and analyzed. In this process, the authors selected and filtered data to fit the LSTM-RNN algorithm. The number of nodes in the input layer, hidden layer, and output layer were installed to train the LSTM-RNN model using the Tensorflow library. During the testing and training process, other factors such as learning rate, activation function, loss function, and the optimizer were found. The target of temperature prediction error was lower than 3%.

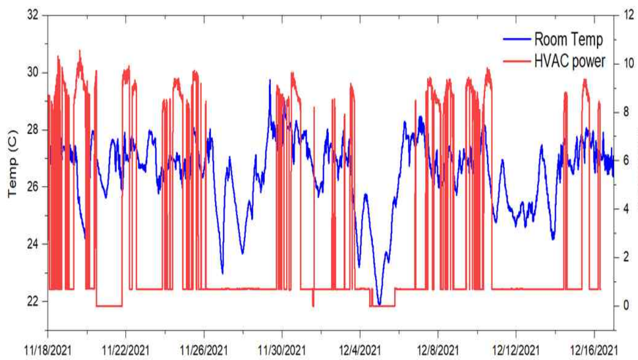
As a result, the model can predict the ambient temperatures with very high accuracy at different times of the day. The minimum error was 1.9%. The results of this study will be used to control HVAC systems ON/OF to save energy in the smart factory.

2. Design of a temperature prediction algorithm using LSTM-RNN

2.1 Temperature data collection and analysis

In this study, the LSTM-RNN algorithm required a dataset as an environment temperature data to build and train the LSTM-RNN model. The temperature data was recorded in real-time from November 18 to December 16, 2021 by the company.

Fig. 1 describes the relationship between the ambient temperature and the energy demand of an HVAC system. The authors realized that the operating capacity of the HVAC system depends on the environment temperature. Therefore, the HVAC system can be controlled ON/OFF following the key temperature points.



<Fig. 1> Relationship between the room temperature data and the power demand of an HVAC system

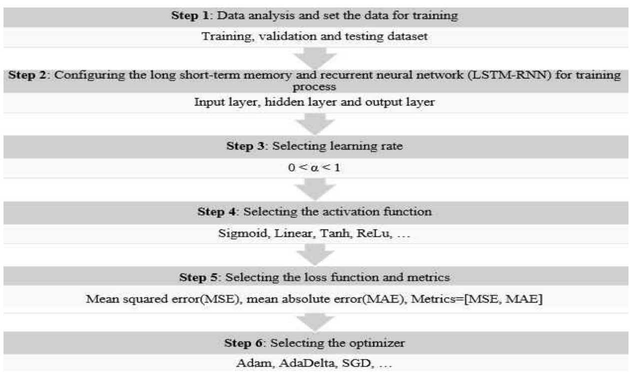
2.2 AI model design process

The design process of the LSTM-RNN algorithm for the temperature prediction is depicted in Fig. 2. The authors started with data collection and analysis. The configuration of the LSTM-RNN algorithm was designed by building the input layer, the hidden layer, and the output layers and defining algorithm factors such as the learning rate, activation function, loss function, and optimizer. Finally, the configuration of the LSTM-RNN algorithm was validated and trained to predict the ambient temperature for the next 15 minutes with an error of less than 3%.

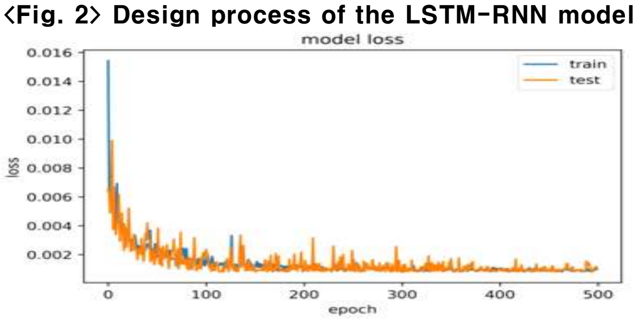
The input of the LSTM-RNN algorithm was the temperature data that was recorded every 15 minutes for 3 days. After changing the parameters and testing several configurations of the LSTM-RNN algorithm, the output of the LSTM-RNN algorithm predicted the temperature with high accuracy. Thus, the most suitable specifications for the LSTM-RNN algorithm were determined as shown in Table 1.

<Table 1> Specifications of the LSTM-RNN algorithm for predicting temperature

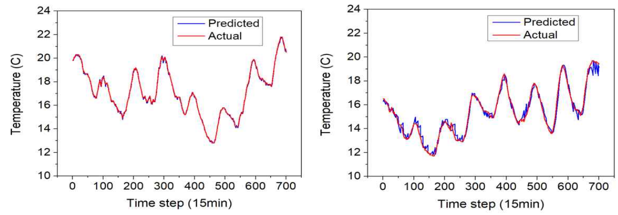
Items	LSTM-RNN model
Number of inputs	288
Number of outputs	1
Number of hidden layers	2
Number of neurons in each hidden layer 1	128
Number of neurons in each hidden layer 2	256
The activation function in hidden layers	Sigmoid, Tanh
The activation function in the output layer	Linear
Adapting learning function	Adam
Learning rate	0.001
Loss function	MSE
Accuracy metrics	SMAPE, MAE



<Fig. 2> Design process of the LSTM-RNN model



<Fig. 3> Training performance of the LSTM-RNN model



(a) (b)

<Fig. 4> Test results and actual results of the LSTM-RNN model: (a) the results of the testing model, and (b) the actual prediction results

3. Results and discussions

The LSTM-RNN model was trained and tested through 500 epochs. As a result, the training performance achieved a mean squared error (MSE) of approximately 0.0015 as shown in Fig. 3. The authors continued to check the function of the LSTM-RNN algorithm by using the testing dataset for the LSTM-RNN model. The results depicted in Fig. 4(a) presented that the LSTM-RNN model worked very well to predict the temperature with the mean absolute error (MAE) reaching about 0.1°C. Finally, applying the LSTM-RNN algorithm for the company to predict temperature. Fig. 4(b) exposed the high model performance in predicting the ambient temperature in real-time from March 18 to March 25, 2022 when using the LSTM-RNN model.

4. Conclusion

This paper had built an LSTM-RNN algorithm to predict the environment temperature for controlling an HVAC system in a smart factory. After training and testing the model, the LSTM-RNN algorithm has shown its strength and superiority when it predicted the ambient temperature with high accuracy. The application of this LSTM-RNN algorithm to predict the temperature in real-time for smart factories will help the authors that can control ON/OFF the HVAC system to manage and save energy.

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[References]

[1] Diana Manjarres, Ana Mera, Eugenio Perea, Adelaida Lejarazu, Sergio Gil-Lopez, " An energy-efficient predictive control for HVAC systems applied to tertiary buildings based on regression techniques " in Energy and Buildings 152 (2017) 409 - 417

[2] Alex Sherstinsky " Fundamentals of Recurrent Neural Network (RNN) and Long Short-Term Memory (LSTM) network " in Physica D: Nonlinear Phenomena 404 (2020) 132306