Technical Report

Nowadays, smart buildings equipped with fully or partially automated system to control the physical environments are becoming increasingly prevalent. Specifically, the physical working environments in office buildings, such as illumination, air quality, temperature and humidity have long been recognized as key features in ambient working environments that exert significant influence on occupants' comfort level and health conditions (Allen, MacNaughton, Laurent, & Eitland, 2015; Deuble, Dear, 2012). Moreover, there have been studies showing that buildings usually account for 30% to 40% of the total energy consumption and carbon dioxide emissions worldwide. Thus, proper indoor-environmental settings can greatly reduce energy usage and thus create more environmental-friendly buildings (Chen, Chou, Duri, Lei, & Reason, 2009).

With the purpose of realizing an automated controlling system in smart office buildings, several students in Dr. Haiying Shen's Pervasive Communication Lab and I proposed a smart building assistance system that consists of sensor data analysis and deep neural network (DNN) based prediction model. Specifically, the proposed system predicts the physical features for current activity so that occupants feel comfortable and their levels of desire are satisfied based on their previous activities and the corresponding physical features. Meanwhile, the proposed system also saves energy as a by-product of offering more comfort to occupants.

We first collect one-year-long smart building datasets from four different data sources (i.e., sensors, calendar, weather, and survey) All datasets are combined and extensive feature engineering is then performed on the collected dataset in order to prepare the raw data for the prediction model. Specifically, this process includes the application of (1) discretization and one hot encoding; (2) multiple-feature combination; (3) extraction of statistical values such as minimum and maximum to expand the feature space; (4) addition of time-series features; (5) 2 feature selection. We then propose a support vector regression (SVR) based prediction model and a hybrid DNN model, which consists of several long short-term memory (LSTM) blocks and a feed-forward DNN block so that different physical features (e.g., lighting, shading, air quality, and temperature) can be predicted for different building activities (e.g., meeting, lunch, and research activities). Eventually, we conduct extensive experimental studies to evaluate the performance of the proposed prediction models with other existing machine learning models in terms of mean absolute percentage error (MAPE) and accuracy.

We also conduct experiments using our collected data to figure out the activity-wise comfort levels and energy saving rates. From the experiments, we conclude that the proposed smart building assistance system is able to increase occupants' comfort level in office buildings by adaptively adjusting indoor environment features such as temperature and humidity. What's more, the proposed system also reduces the difference between indoor and outdoor temperatures and contributes to energy saving by smartly reducing the workloads of control systems such as air conditioning system when the office is not occupied.

In the future, we will focus on the following tasks: (1) Investigation on the interpretability of our automatic control system to make each adaptation of factors understandable to humans by adding reasoning with changes. (2) Integration of human knowledge or customized settings in separated building assistance systems. For example, users in different rooms may have different preferences. We will further explore different machine learning algorithms to take personal preferences into consideration. (3) Improvement on the robustness of our proposed system. DNN-based applications are sensitive to minor changes in the inputs and thus might be vulnerable to adversarial attacks. Improving the robustness of the system and avoiding malicious manipulations of indoor factors might be essential concerns in safety-critical scenarios such as a room that contains explosives which might explore when exposed to improper temperature conditions.