Demand Response Enabled Artificial Intelligence based Air Conditioning System

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***Abstract*—Recently, as energy smart metering and remote control of smart devices become possible, Demand Response (DR) in home and small building is increasing. In this paper, we propose a DR enabled AI based air conditioning system to overcome the energy shortage problem in summer. It derives users' comfortable temperature by learning temperature and humidity, and automatically controls the air conditioner based on derived temperature. In addition, when DR is issued, the energy peak control based on the Predicted Mean Vote (PMV) is performed, thereby minimizing the user comfort degradation and finding DR resource. The experiment was conducted based on the test bed and we have shown its feasibility.**

Keywords–Demand Response; Artificial Intelligence; Predicted Mean Vote; Air Conditioning System

I. INTRODUCTION

Demand for energy continues to globally increase and a tremendous social expense is required to recover from the yearly arising blackouts. In recent years, there has been a growing concern about the energy shortage, as the energy consumption in summer and winter has increased sharply due to abnormal climates, such as heat and cold waves [1].

Demand Response (DR) refers to a technology that balances energy demand and supply by adjusting electricity rate and instructing load reduction when energy supply crisis arises. Previously, DR studies mainly carry out to prevent power outage in the factory or building. However, as remote control of various home appliances in the smart home has become possible thanks to the improvement of the Internet of Things technology, DR in home and small buildings is also being studied [2].

In this paper, we have proposed DR Enabled Artificial Intelligence based Air Conditioning System to overcome the energy shortage problem due to soaring energy use in the summer. The air conditioning system predicts the Predicted Mean Vote (PMV) [3] of each home using artificial intelligence technology and automatically controls the air conditioner based on the derived temperature by PMV. When DR signal is issued, the air conditioning system adjusts the temperature of each home according the learned PMV that reflects user's preferred comfort level. The experiment was conducted based on the test bed and we have shown its feasibility.

The rest of this paper is organized as follows. Section II describes the system design, and Section III evaluates the proposed system by conducting the experiment. Finally, we conclude this paper in Section IV.

II. DESIGN OF AI BASED AIR CONDITIONING SYSTEM

Figure 1 outlines the proposed AI-based Air Conditioning System. It is comprised of the air conditioner controller, the database server, and the learning and control system. The air conditioner controller plays a role in sending a control data by the remote controller and periodically measured environmental data (e.g., temperature, humidity, occupancy) to the database server. Since it is equipped with an IR transceiver, IR signal sniffed from the remote controller can be converted into a control message.

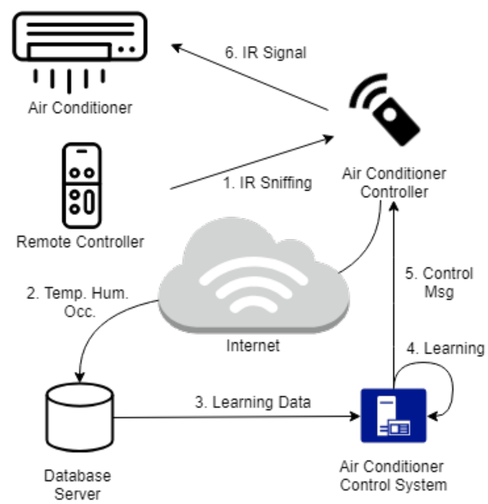

Figure 1. Overview of AI based Air Conditioning System

The database server plays a role in storing data sent from the air conditioner controller through RESTful web APIs. The data includes temperature, humidity, and occupancy. Occupancy data is expressed as 0 (unoccupied) or 1 (occupied) to determine if the user is occupying the home.

The learning and control system learns the temperature and humidity data obtained from the database server and generates PMV learning model using an artificial neural network. The temperature and humidity data is not used for learning when the occupancy data is 0, and PMV stands among the most recognized thermal comfort models that express satisfaction with the thermal environment.

After the PMV learning model is generated, it derives the current comfortable temperature of the home by assigning the current humidity as a parameter to the PMV learning model and sends the control message containing the derived temperature to the air conditioner controller every 10 minutes. The air conditioner controller generates IR signal corresponding to the received control message and controls the air conditioner.

The control mode is divided into comfort and economy

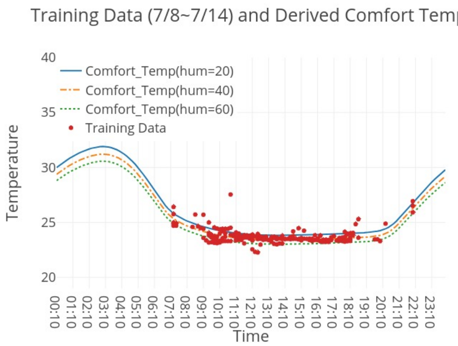

Figure 2. Training Data and Predicted Comfortable Temperature Graph based on PMV Learning Model

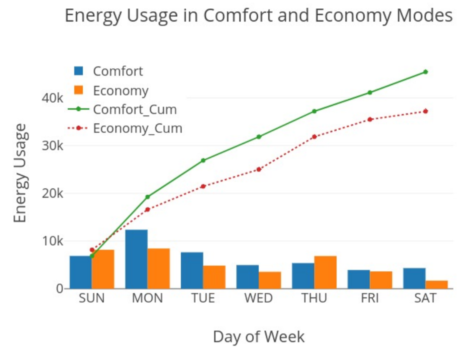

Figure 3. Comparison of Energy Usage in Comfort (7/15-7/21) and Economy (7/22-7/28) modes

modes which are set by users' smartphone. In the comfort mode, the air conditioner is controlled by the derived comfortable temperature, and in the economy mode, it is controlled to be 2 degrees higher. However, if the user changes the temperature while the air conditioner is operating automatically, the adjusted temperature is added to the previous training data for the next learning. This allows the user's intention to be continuously reflected in the training data, thereby improving the user's satisfaction.

When the DR signal is issued, the air conditioner control system queries the user through the smartphone whether to join the DR. For the users joining the DR, their air conditioner is controlled so as to minimize the difference between the adjustable PMV and the learned comfortable PMV to minimize the deterioration of the user comfort. This can be expressed by the following equation;

$$Minimize : \sum_{i=0}^{N-1} |PMV(i) - cPMV(i)| \qquad (1)$$

where $PMV(i)$ is adjustable PMV of home i through temperature control when the DR signal is issued, $cPMV(i)$ is learned comfortable PMV of home i, and N is the number of houses participating in DR. According to the above equation, the air conditioner is initially controlled by assigning $cPMV(i)$ to $PMV(i)$ which minimizes $|PMV(i) - cPMV(i)|$. However, if the amount of energy saved is insufficient, $PMV(i)$ increases until it reaches the target energy savings. This minimizes the deterioration of comfort by DR.

III. Experiment and Evaluation

Experiments based on the test bed were carried out to verify the feasibility of the proposed AI based air conditioning system. The test bed was constructed at a room in Korea Electronics Technology Institute. We collected temperature, humidity, occupancy data of the room from July 8th to 14th, 2018 and generated the PMV learning model based on these data. Note that actual test bed will be extended in the future.

Figure 2 shows the training data of temperature for 7 days, and the predicted comfortable temperature graph derived from PMV learning model. The dots represent training data, and the solid, dashed-dotted, and dotted lines show a comfortable temperature graph in humidity 20, 40, 60, respectively. The learning data distribution and the derived comfortable temperature graph have a similar pattern, which shows that the derived comfortable temperature reflects the user's preference. Using this derived comfortable temperature while DR operates, the air conditioner is controlled according to the comfort level, minimizing the deterioration of comfort in the home and encouraging participation in the DR.

Figure 3 shows the energy usage difference between the comfort (7/15-7/21) and economy modes (7/22-28). The left and right bars on day of week show daily energy usage in the comfort and economy modes, and the solid and dotted lines show cumulative energy usage in the comfort and economy modes. The difference between cumulative energy usage in economy and comfort modes shows a tendency to increase with time. Comparing these on Saturday, the economy mode uses about 8.2 kW (= 45437-37168) less than the comfort mode. This represents the amount of electricity that can be saved by controlling the temperature, which can be used to determine the amount of temperature that needs to be adjusted to meet the target energy savings during DR operation.

IV. Conclusion and Future Work

In this paper, we have proposed the demand response enabled artificial intelligence based air conditioning system. The proposed system generates the PMV learning model by learning temperature and humidity data, and performs PMV based air conditioner control considering the user comfort level when the demand response signal is issued. Experiments were performed on a test bed and showed the feasibility of the proposed system. For future research, we will apply current work to the large scaled test bed and measure the performance.

Acknowledgment

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