Poster: INPRESS - Indoor Climate Prediction and Evaluation System for Energy Efficiency using Sensor Networks

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Abstract

Modern buildings include an indoor climate control system, installed and operated to maintain a comfortable environment for the building occupants. However, these climate control systems consume a significant amount of energy due to an inefficient control algorithm. Improving energy efficiency is critical to reducing energy consumption, costs, and the emissions of greenhouse gases. In this paper, we present **INPRESS**: **In**door Climate **Pr**ediction and **E**valuation **S**ystem for Energy Efficiency using **S**ensor Networks. INPRESS uses meteorological weather data and the indoor climate conditions collected by sensor nodes to evaluate and improve the energy efficient climate control of an indoor space.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*; C.3 [**Special-Purpose and Application-Based Systems**]: Real-time and Embedded Systems; H.4 [**Information Systems Applications**]: Miscellaneous

General Terms

Experimentation

Keywords

Sensor Network, Indoor Climate, Energy Efficiency

1 Introduction

An indoor climate control system maintains a uniform and comfortable temperature and relative humidity level throughout a building, providing high level of thermal comfort. The human thermal comfort is defined as the state of mind that expresses satisfaction with the surrounding environment and correlates to the productivity of daily tasks carried out in an indoor space [1]. Most modern control systems fall short of efficiently regulating the climate of an indoor space in two main ways. First, the control systems operate without considering how the changes in outdoor weather conditions affect the indoor conditions. Second, the systems treat a room as a single zone, although different parts of a space have different environmental conditions [3]. These two factors can cause a significant amount of energy waste. To address these limitations and significantly improve the energy efficiency of indoor climate control systems, we present INPRESS. INPRESS uses meteorological weather data and indoor climate conditions collected by sensor nodes in different areas in a room to construct a multivariate dynamical model that describes the relationship between weather conditions and indoor climates of different areas. With this model, INPRESS can predict indoor climate conditions for the near future with a high degree of accuracy. With these predictions, INPRESS can evaluate and improve the energy efficiency of the climate control system.

2 Architecture Overview

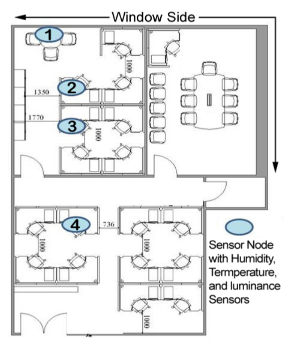

Figure 1. Sensor Layout

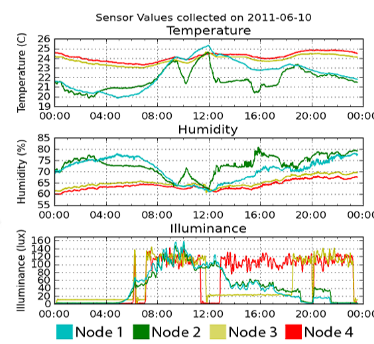

Figure 2. Sensor Values

To test the use of the sensor nodes, TelosB-compatible sensor nodes running TinyOS were deployed throughout an office room of a commercial building located in the Seocho district of Seoul, Korea (see Figure 1). Each sensor node gathered three types of climate data: temperature, humidity, and luminance (see Figure 2). The collected data was sent to a gateway, which stored it in a database server. The sensor nodes and the collected data were the property of Korea Electronics Technology Institute and we were given permission to access the database during the course of this research project. We also gathered past weather records and forecasts for the Seocho district, including temperature, humidity, and the amount of cloud cover, from the Korea Meteorological Administration via the Web.

3 Experimental Results

The initial task for this experiment was to validate our assumption that there is a correlation between indoor climate and outdoor weather conditions. The cross correlation as-

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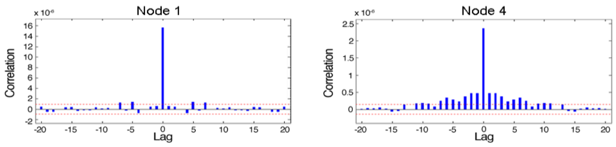

Figure 3. Error auto-correlation

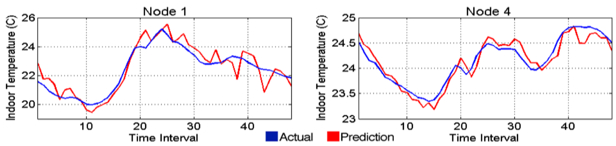

Figure 4. Prediction of Indoor Temperature

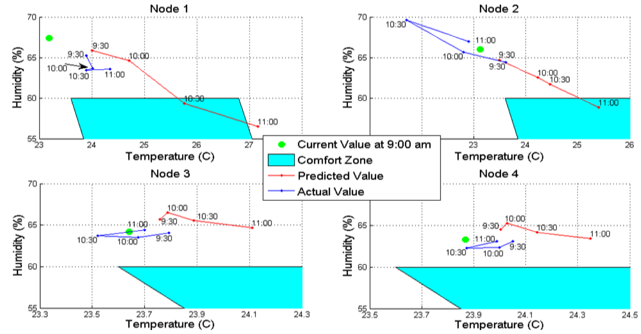

Figure 5. Thermal Comfort Zone Analysis

sessment of these time-series data was performed to validate this assumption by using three graphical tools: time series, lagged scatter, and cross correlation plots. The assessment revealed that nodes 1 and 2 are significantly affected by the outdoor weather conditions while nodes 3 and 4 are less affected by it. The next task was to construct a model that describes the above relationship. Because constructing a multivariate time-series model with delay is a highly complex task, we used an artificial neural network model to facilitate such process [2]. For our purpose, we used the nonlinear auto-regressive network with exogenous inputs (NARX), a recurrent neural network commonly used in time-series modeling. First, we configured the neural network model with supervised training data. Each training data consisted of a set of past weather conditions of the Seocho district as an input and a set of actual indoor climate conditions collected from the four sensor nodes in the office as a desired output. We prepared the training data using the weather records and sensor values for May 2011. Figure 3 shows error autocorrelation plots of nodes 1 and 4, which are used to validate the model performance. We have chosen these two nodes to show that the regions at both the window and inner sides of the building conform to our prediction model. Each subplot shows a large error value only at zero, which indicates that the prediction errors were uncorrelated in time. Next, we used the local weather forecast data to predict the indoor climate of future time intervals. To perform prediction, the model requires two input values: the current indoor climate and weather conditions. The predicted and the actual indoor temperature values of nodes 1 and 4 are shown in Figure 4, which illustrates that the prediction is in good agreement with the actual sensor values.

Next, we evaluated the efficiency of the climate control system by using the prediction model. For the evaluation, we chose a particular time of the day (9:30 am on June 10th, 2011) when dramatic changes in both indoor humidity and temperature occurred due to air conditioning. From one time interval before the chosen time, which is 9:00 am, the prediction for the four consecutive time intervals (2-hour span) was calculated to observe the trends in indoor conditions without air conditioning during the course of this evaluation. Figure 5 shows both the predicted and actual indoor conditions. In each plot of the figure, where the x-axis represents temperature and the y-axis represents humidity, we present an object filled with cyan, which represents the thermal comfort zone. The thermal comfort zone is the specified range of humidity and temperature values defined by ASHRAE. We observed that as time passed, the predicted conditions of nodes 1 and 2 located near office windows, approaches the comfort zone. However the actual conditions of these nodes performed worse in terms of thermal comfort. This shows that the air conditioning was not necessary for the regions of these nodes. For nodes 3 and 4, both the predicted and actual indoor conditions never achieved the thermal comfort. Although it requires more data to evaluate the energy efficiency of these regions, we can conclude from this result that different regions of the room require different ways to control the indoor climate conditions.

4 Discussion and Future Work

In this experiment, we evaluated the energy efficiency of the climate control system by using the predicted temperature and humidity values based on the weather forecast and sensor node data, without knowing how the system would actually respond to current indoor conditions.

In order to achieve better energy efficiency, first, we will build a database that consists of the behaviors of the climate control system in relation to the outdoor weather conditions and their impact on indoor climate conditions for given time frame. Also, we will keep a record of power consumption for each behavior of the system. This data can be readily retrieved from a modern building with a centralized climate control system, which was not available in the building that we collected the sensor data. Second, we will categorize the different behaviors into groups of similar weather conditions. With these data, we can improve the evaluation of the climate control system by building another neural network model that describes how the system is going to respond to a given indoor climate conditions and how much energy will be used to achieve the thermal comfort in the building.

For more information, please visit the project website at *www.irisen.org/INPRESS*.

5 References

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