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Computational Intelligence based Anomaly Detection for Building Energy Management Systems

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Outline

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- Motivation
- Feature Extraction
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  - Anomaly Detection
  - Linguistic Summarization
- Implemented tool:
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  - Anomaly detection tuning
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- Conclusion and future work

Introduction

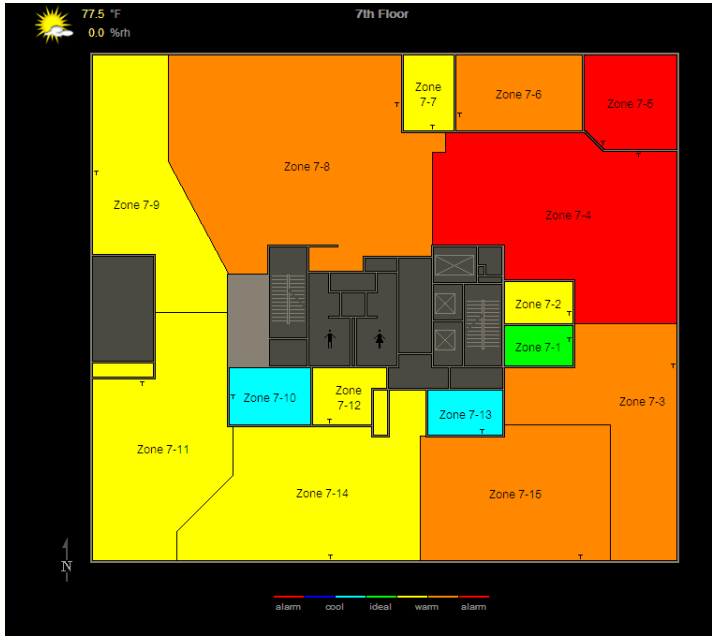
- Significant portion of building energy usage is by HVAC systems
  - Over 50%
- Building Energy Management Systems (BEMSs) are used to control these systems
  - Advanced and highly complex
- BEMSs gather data from a large number of sensors throughout the building:
  - Temperature
  - CO_2
  - Occupancy
  - AHU performance, etc.
- Proper tuning of BEMSs allow significant savings
- Highly complex therefore difficult to understand:
  - Low situational awareness

Anomaly Detection for Building Energy Management Systems

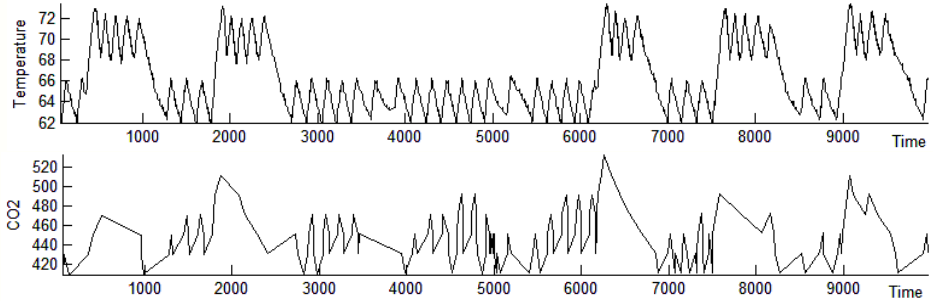
- Problem:
  - How to improving the understandability of Building Energy Management Systems (BEMS)?
    - How to help building manager navigate in and understand the spatially complex building data
- Solution:
  - Increase the state-awareness of building managers via anomaly detection techniques
    - Reducing the complexity of the presented information
    - Automatic identification of interesting patterns in building performance
    - Automatic generation of building performance summary reports
    - Easy to understand natural linguistic description of identified anomalies

Feature Extraction

- BEMS provide large amount of complex data
- Data Hierarchy
  - Building -> Floor -> Occupant's Zone



Zones Measurements



Extracted Features *:

1) Temperature
2) Temperature Gradient

* Note, adding more features is scope of future work.

Anomaly Detection

- Learns model of **normal** occupant's zone behavior
  - Applies Nearest Neighbor clustering to the time sequence of historical building data
  - Accumulate statistical information about the patterns assigned to each cluster

- Cluster attributes:

$$P_i = \{\vec{c}_i, w_i, M_i\},\ \vec{c}_i = \{c_i^1, \ldots, c_i^n\},\ M_i = \begin{vmatrix} \overline{c}_i^1 & \cdots & \overline{c}_i^n \\ \underline{c}_i^1 & \cdots & \underline{c}_i^n \end{vmatrix}$$

- Modified cluster update rule for the Nearest Neighbor clustering:

$$\vec{c}_a = \frac{w_a \vec{c}_a + \vec{x}_i}{w_a + 1},\ w_a = w_a + 1$$

$$\overline{c}_i^j = \max(x_i^j, \overline{c}_i^j),\ \underline{c}_i^j = \min(x_i^j, \underline{c}_i^j) \quad j = 1 \ldots n$$

Fuzzy Rule Extraction

- During the testing phase, individual clusters are used to initialize fuzzy rules:

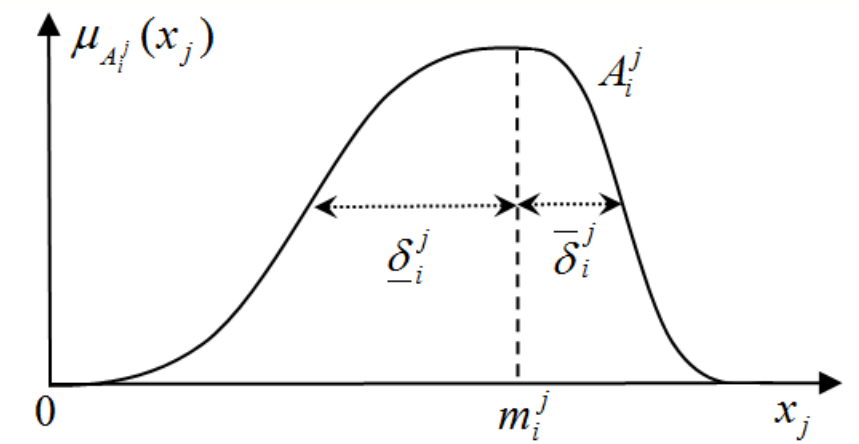
Rule R_k: **IF** x_1 is A_1^k **AND** … **AND** x_n is A_n^k **THEN** y_k is B^k

- Gaussian fuzzy set:

$$m_i^j = c_i^j$$

$$\overline{\delta}_i^j = \alpha(\overline{c}_i^j - c_i^j)$$

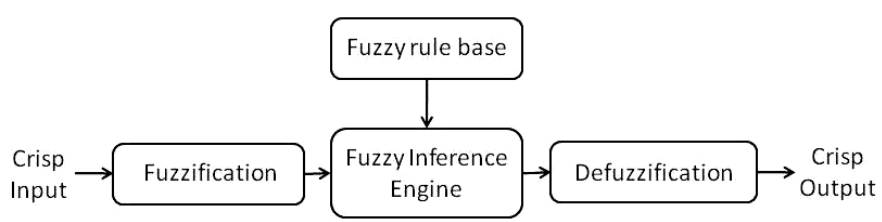
$$\underline{\delta}_i^j = \alpha(c_i^j - \underline{c}_i^j)$$



α - Fuzzines parameter

Fuzzy Rule Based Anomaly Detection

- Uses fuzzy inference with the extracted set of normal occupant's zone behavior rules:



- Fuzzy Rules: Rule R_k: **IF** x_1 is A_1^k **AND** … **AND** x_n is A_n^k **THEN** y_k is B^k

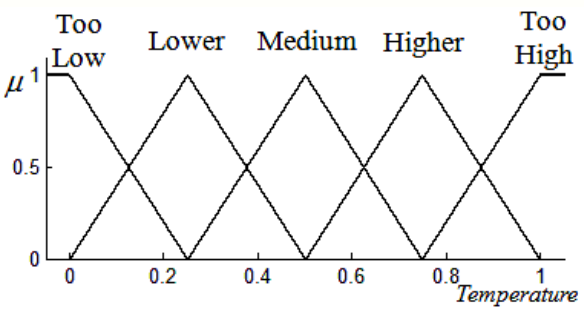
- Degree of Firing: $\mu_{R_i}(\vec{x}) = \min_{j=1\ldots n}\{\mu_{A_i^j}(x_j)\}$

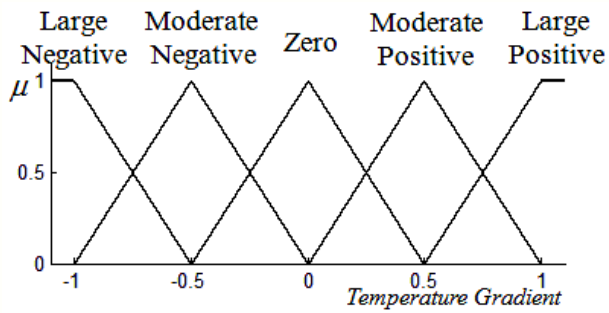
- Aggregate rule outputs: $y(\vec{x}) = \max_{i=1\ldots C} \mu_{R_i}(\vec{x})$

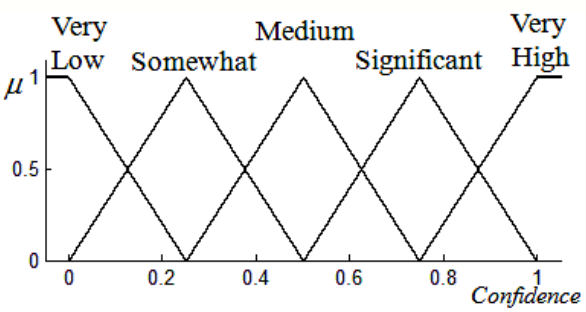
  – Rules describe the similarity of the observed behavior and the normal behavior.

Linguistic Description of Anomalies

- Identified anomalies can be described using easy to understand linguistic rules
  - Improves the understandability of the results by building managers
  - Linguistic labels are computed by fuzzifying the feature vector and then selecting linguistic terms with maximum membership grades





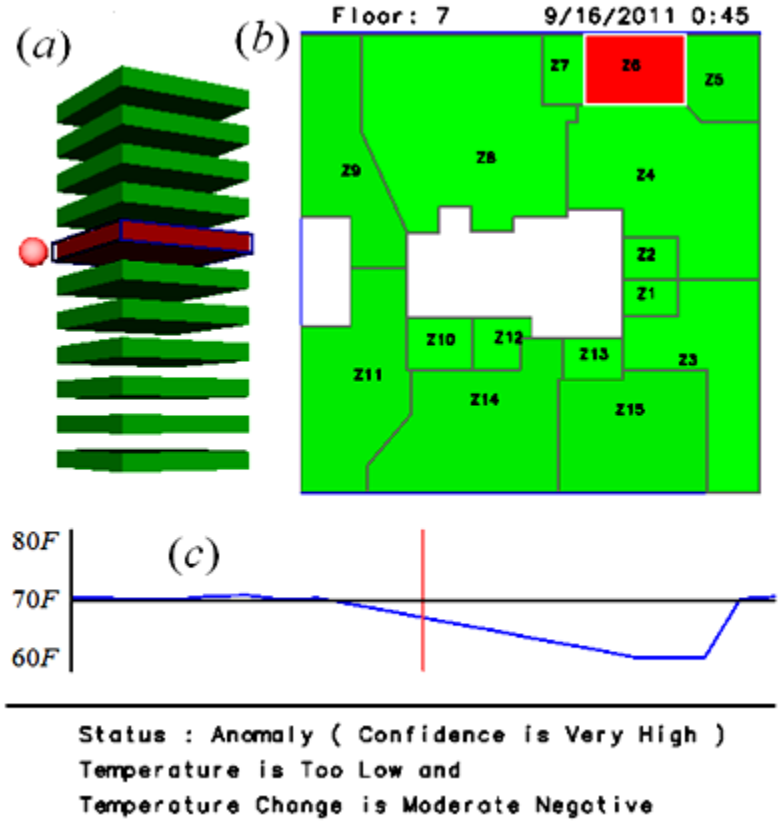


  - E.g. **Temperature** is *Too Low* and **Temperature Change** is *Large Negative* (**Confidence** is *Very High*).

Note, the confidence value is taken as (1 – output) of the anomaly detection algorithm

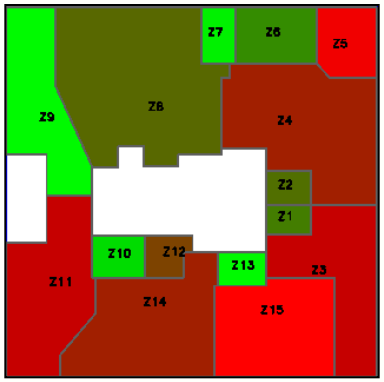
Developed System Overview

- Hierarchical view of the building
  - Building, floor and data view

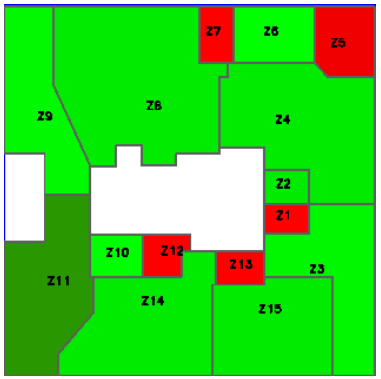


Different visualization modes

Temperature



Anomaly



Data Analysis

- Sequential exploration of data
  - Every time sample – overwhelming task
  - Identified anomalies (rapid scanning of historical data)

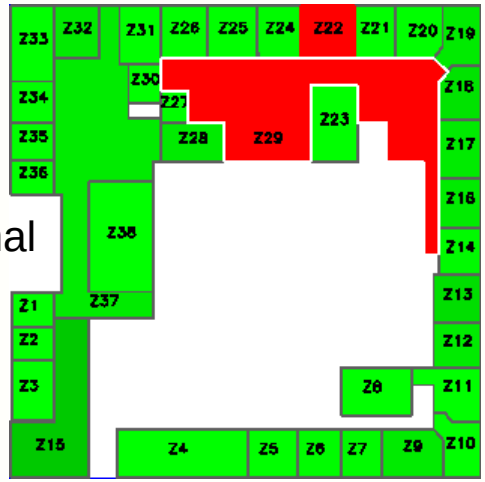
- Automatic summary report generation:

Location	Time	Linguistic Description
Floor 7, Zone 7	9/16/2011, 3:45am – 6:45am	**Temperature** is *Too Low* and **Temperature Change** is *Large Negative* (**Confidence** is *Very High*).
Floor 7, Zone 6	9/16/2011, 0:45am – 7:30am	**Temperature** is *Too Low* and **Temperature Change** is *Moderate Negative* (**Confidence** is *Very High*)
Floor 7, Zone 11	9/16/2011, 9:00pm	**Temperature** is *Medium* and **Temperature Change** is *Large Negative* (**Confidence** is *Very High*)
Floor 7, Zone 2	9/19/2011, 12:45pm:	**Temperature** is *Too High* and **Temperature Change** is *Large Positive* (**Confidence** is *Significant*)
Floor 7, Zone 7	9/22/2011, 7:30am – 8:15am	**Temperature** is *Too Low* and **Temperature Change** is *Large Positive* (**Confidence** is *Very High*)
Floor 5, Zone 37	9/23/2011, 8:15pm	**Temperature** is *Lower* and **Temperature Change** is *Large Negative* (**Confidence** is *Very High*)
Floor 5, Zone 2	9/24/2011, 7:30pm – 8:15pm	**Temperature** is *Medium* and **Temperature Change** is *Large Negative* (**Confidence** is *Very High*)
Floor 5, Zone 23	9/25/2011, 11:15am – 12:00pm	**Temperature** is *Higher* and **Temperature Change** is *Moderate Negative* (**Confidence** is *Very High*)
Floor 5, Zone 17	9/26/2011, 9:00am	**Temperature** is *Too High* and **Temperature Change** is *Moderate Positive* (**Confidence** is *Significant*)

Anomaly Detection Tuning

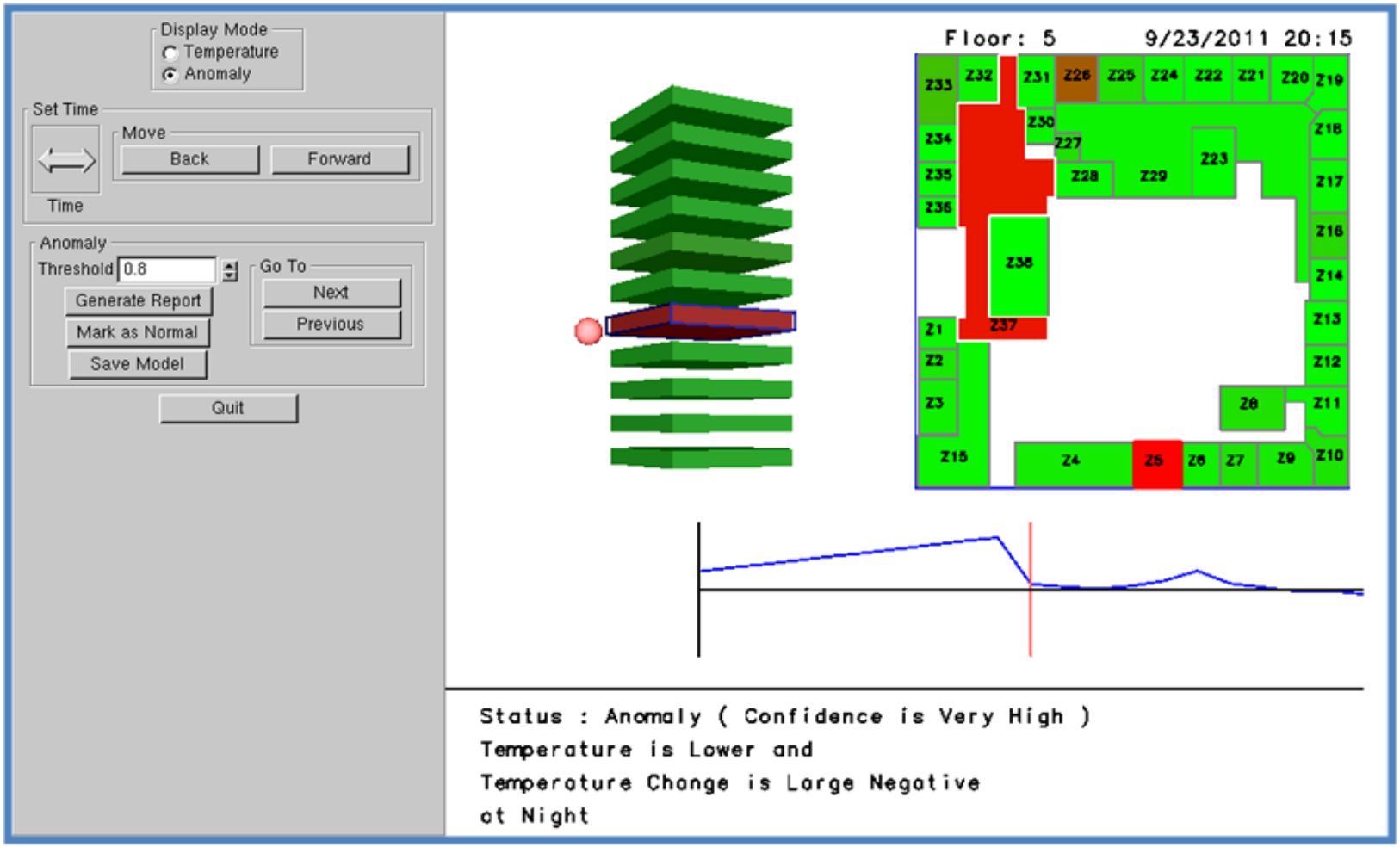
- Identified Anomalies
  - Based on **significant difference** from provided normal training data
  - Not necessarily anomalous building behavior
- Operator's **background knowledge** can be used to tune the performance of the anomaly detection algorithm
  - Identified anomalies can be added to the normal behavior model upon request
  - Selected feature vector is re-clustered and new FLS is generated

Original



After Update

Graphical User Interface



Future Work

- Integrating additional sensor data to the anomaly detector
  - E.g. CO2 level, occupancy, user comfort
- Codifying different types of anomalies. Implement methods for searching for specific anomalous behaviors.
- Defining what kinds of actionable information can be provided to building managers
- Designing and integrating predictive modeling tools
  - E.g. some anomalies can be likely detected ahead of time.
- Implementation for building managers
  - Tablet/phone (android)