SEMANTICS-DRIVEN MIDDLEWARE LAYER FOR BUILDING OPERATION ANALYSIS IN LARGE-SCALE ENVIRONMENTS

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Outline

• Introduction
  • Facility management
  • Information systems in facility management

• Motivation and Goals
  • Use case: University campus of Masaryk University

• Problem: Automation data analysis

• Method: Automation data semantics and querying

• Results, Summary, Conclusions
Facility Management

• According to IFMA (International Facility management association): „a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology“

• FM ensures tasks, which are not part of organization’s „core business“
IS in Facility Management

**BIM**
- BIM = Building Information Model
- Built environment, locations and devices
- Generally static data

**CAFM**
- CAFM = Computer Aided Facility Management Software
- Space management, Furniture, Maintenance, Energy management
- Dynamic data (e.g. financial, HR), uses BIM data
- Analysis & Reporting

**BMS**
- BMS = Building Management System
- Remote monitoring and control of building automation systems
- Recent (present) and historical data from sensors and other devices
BIM – Building Information Model

• Digital representation of a building

Source: Authors
CAFM – Computer-Aided Facility Mgmt

- CAFM software supports:
  - Space management
  - Maintenance
  - Energy management
- Provides advanced analytical tools

Source: Archibus, Inc.
Smart buildings

• Devices in buildings connected to a network
  • Heaters
  • Air conditioning units (HVAC)
  • Lighting
  • Energy meters
  • ...

• Monitored and controlled remotely
Smart buildings – Approaches

Modern (Households & SOHO/IoT)
• „We have cheap computers, can we use them to control appliances?“
• Origins in ICT

Traditional (Large sites)
• „We have lot of devices in a building, can we facilitate the management?“
• Origins in civil engineering & electronics engineering
Smart buildings – Approaches

Households & SOHO/ IoT

- Examples:
  - Arduino
  - .NET Gadgeteer
  - Energomonitor
  - Nest/Google thermostat
- Relatively cheap

Large sites

- Technologies
  - Building Automation Systems
  - Building Management Systems
- Expensive
- Long device lifetime
- Compliance to standards
Smart buildings – Approaches

Households & SOHO/IoT

- Devices using:
  - Operating system
  - Wi-Fi
  - HTTP
  - Web services
  - Cloud
  - M2M, Internet of Things

- Controlled by
  - Web interface
  - Smart phones

Large sites

- Devices using
  - Microcontrollers
  - Serial bus (RS232, RS485), Ethernet, TCP/IP
  - Specialized automation protocols

- Controlled by
  - Dedicated desktop applications
  - Web interface
Smart buildings – Approaches

Households & SOHO/IoT

- ARM Cortex A8
- 40 MB flash

Large sites

- CPU 25 MHz
- 128 kB RAM
- 1 MB flash

Source: Google, Inc.

Source: Delta Controls, Inc.
Smart buildings – BAS & BMS

• **BAS** = Building Automation System
• **BMS** = Building Management System
• Used mostly at large sites
• Ensures automated operation of building technologies:
  • **HVAC**
  • **Lighting**
  • **Safety & Security systems (Fire alarm, Access control)**
  • **Elevators**
  • **Energy monitoring**
Smart buildings – BAS & BMS

- Remote monitoring and control
- Integration of different systems
- User interface
- Alarming
- Archiving
- Regulation algorithms
- Scheduling
- Cooperation
BMS – PLCs

- **PLC** = Programmable logical controller
- Specialized computer for automation
- Provides various types of input and outputs
  - **Analog inputs** – e.g. temperature, humidity, pressure sensors
  - **Analog output** – e.g. valve opening
  - **Digital (discrete) inputs** – e.g. motion sensor
  - **Digital (discrete) outputs** – e.g. fan speed, relay control
- Programmable by specialized tools & languages
BMS – PLCs

Source: OFM SUKB MU

Source: siemens.com
BMS – Structure

Source: Authors
BMS – UI

Source: OFM SUKB MU
BMS – UI

*Source: OFM SUKB MU*
Motivation – Use case

- **Goal:** Examining building operation *performance* and *efficiency* using BMS data
- **Use case:** BMS of Masaryk University (40 buildings, 150 000 data points)

*Source: muni.cz*
Motivation – Analytical capabilities

**BMS**
- Sensor data
- High detail
- Recent data
- Simple applications

**CAFM**
- Financial data
- Low detail
- Delayed data
- Complex applications

- How much does the electricity consumption differ across the campus?
- How much energy is consumed by air conditioning?
- What are the average room temperatures?
BMS vs. Big Data

- **Volume** does not apply
  - 150,000 data points, Up to 10GB of useful data/year
- **Velocity** does not apply
  - Polling frequency: minutes
  - Change of Value (e.g. 1°C)
- **Variety** does apply (partially)
  - Structured data
  - Undifferentiated data types (Temperature, Humidity, Setpoint, …)
- **Variability & Veracity** do not apply
  - Data are consistent, credible and of high quality
Problem – Complexity

• Application development tasks:
  • Data access (automation protocols, OLTP)
  • Data selection, grouping & aggregation
  • Analytical methods
  • User Interface
Problem – Unsuitable semantics

- Data points **identified by** network **address** in BMS
  - BACnet protocol: 25104.AI101
- Data point properties carry **limited semantics**:
  - Object type (Analog/Binary/..., Input/Output/Variable/...)
  - Engineering units
- **Missing relation** to the physical world:
  - Location
  - Source device
  - Measuring environment (air, water, ...)
  - ...
Aims & Methods – New semantics

• New approach to analysis of BMS data
  • Network **addresses are not used** as identifiers
  • Universal model relates **BMS** and **BIM** and also adds new information

![Diagram with nodes and connections]

- Network address (BMS)
- Location (BIM)
- Source device (BIM)
- Meaning (New)
- Purpose (New)
- Physical quantity
- Environment
- Time window
- Aggregation
Aims & Methods – Ontology

- New semantics of BMS data can be described by **Ontology language**
- **OWL** – Web Ontology Language (W3C)
  - Designed for **Semantic web & Linked Data**
  - Based on **RDF** (Resource Definition Framework)
  - „Subject-Predicate-Object“

[Image of W3C logo]
Aims & Methods – Existing ontologies

- **Upper** ontologies – describe general concepts across domains (not used in our use case)
- Semantic Sensor Network ontology – unsuitable
  - Uses upper ontology as a base
  - Complicated querying
  - Focuses on different concepts
    - SSN: Relation between observation and obtained value
    - BMS: Relation between source device and value, description of measured value
Aims & Methods – Ontology

Source: Muhammad Asfand-e-yar, FI MU
Aims & Methods – Ontology querying

- Ontology repositories can be queried using specialized query languages (SPARQL)

Source: Muhammad Asfand-e-yar, FI MU
Aims & Methods – Ontology tools

• **Protégé** – Open source ontology editor
• **Apache Jena** - Open Source ontology framework
  • OWL/RDF Java API
  • **SPARQL** engine
  • **TDB** - Native (noSQL) persistent **triplestore**
• **Fuseki** – standalone RESTful web server

Source: http://protegewiki.stanford.edu/
Aims & Methods – APIs

- Simplification of application development & integration
- Data access APIs
- Semantic API
  - Encapsulating OWL & SPARQL
  - Domain-specific operators – aggregation, grouping & filtering according to:
    - Location
    - Source device
    - Meaning
    - ...
  - Ready-to-use functions for frequent queries
Aims & Methods – Middleware layer

Source: Authors
Query examples

1. Semantic query
   Location: Campus Bohunice; Building A11
   Grouping: Per floor
   Measured value: Room temperature
   Source device: Temperature sensor
   Data type: Historical data
   Desired output: Network address

2. Semantic result
   N01: {11400.TL5, 11500.TL5, 11600.TL1}
   N02: {12100.TL5, 12300.TL3, 12400.TL5}
   N03: {12500.TL1, 12600.TL1, 12800.TL1}

3. Data query
   Data points: Semantic result data
   Aggregate: temporal AVG
   Period: 09/2014 – 1/2015
   Aggregation Window: 1 day

4. Data result
   N02: {...}
   N03: {...}
1. **Semantic query**
   - Data type: *Input; Output; User defined value*
   - Influenced value: *Room temperature*
   - Influenced location: *Room 231 at building UCB-A11*
   - Desired output: 
     - *Source device (with Location); Network address; Data type; Meaning (quantity)*

2. **Semantic result**
   - *Pump in UCB-A11-1S05, 10200.AO1, Output, Pump mode (on/off)*
   - *Temperature sensor in UCB-A11-1S05, 10200.AI5, Input, Water temperature*
   - *Application controller in UCB-A11-1S07, 10000.AV4, User defined value, Setpoint temperature*

3. **Data query**
   - Data points: *Semantic result data*
   - Aggregate: *- (present value)*

4. **Data result**
   - *Pump in UCB-A11-1S05; ON*
   - *TS in UCB-A11-1S05, 76.5 °C*
   - *AC in UCB-A11-1S07, 22 °C*
Results

- Architecture design
- End-user applications
- Data access API
- Semantic model

Source: Authors, Petr Zvoníček, FI MU
Summary & Conclusion

• **Area:** Building operation analysis using data from automation systems

• **Aims:**
  - Provide new semantics to BMS data
  - Simplify development of analytical tools

• **Method:** Middleware layer
  - Semantic information – Integrating BMS and BIM
  - Data access

• **Evaluation:** Implementation of benchmarks defined in *EN 15 221: Facility Management*