SensorAct: A Privacy and Security Aware Federated Middleware for Building Management

Pandarasamy Arjunan\textsuperscript{1}, Nipun Batra\textsuperscript{1}, Haksoo Choi\textsuperscript{2}, Amarjeet Singh\textsuperscript{1}, Pushpendra Singh\textsuperscript{1}, Mani B. Srivastava\textsuperscript{2}

\textsuperscript{1}IIIT-Delhi, \textsuperscript{2}UCLA

ACM BuildSys 2012
Motivation

- Richer ecosystem for sharing building resources (both sensing and actuation) across several collaborators.
- Globally distributed Indo-US testbed raises challenges not encountered in a building and campus scale deployments.
Motivation

- **Privacy & Security**
  - Selective Data Sharing
  - Protected Actuation
  - Behavioral Privacy

- **Sense- Decide- Actuate**
  - Closing Control Loop within Middleware to Address Latency

- **Diverse Sensors and Actuators**
  - Electricity, Water, Gas, Occupancy, and More

- **Existing systems**
  - Building Scale: Trane, Johnsoncontrols, etc.
  - Home Scale: Micasaverde, etc.
  - Cloud-based: Cosm, Thingspeak, etc.

- Provide some support in each one of these requirements.
- Not scale to globally distributed testbed across organizations.
SensorAct in a Nutshell

• Our Goals

  ‣ Scalable
    - Deployable from homes to across organizations

  ‣ User-Centric
    - Participatory engagement of occupants

  ‣ Versatile
    - Diverse sensing, actuation, and applications

A Tiered and Distributed Architecture

Powerful Sensor and Actuator Guard Rules

Lightweight Tasking Framework

Support Diverse Applications and Researches

Energy (electricity, water, and gas) management

Sustainable buildings

Resource management and utilization analysis
Introducing SensorAct Architecture

Users

VPDS Owners
SensorAct Users

Brokers

Manages Multiple VPDS

Virtual Personal Device Servers (VPDS)

VM Server hosting Multiple VPDS
Dedicated VPDS (e.g., Home Computers)

Devices

Device 1
Device 2
Device n
SensorAct Devices

Users

| VPDS Owners | SensorAct Users |

Brokers

| Manages Multiple VPDS |

Virtual Personal Device Servers (VPDS)

| VM Server hosting Multiple VPDS | Dedicated VPDS (e.g., Home Computers) |

Devices

| Device 1 | Device 2 | ... | Device n |
SensorAct Devices

• Supporting diverse COTS or custom sensors and actuators with diverse interface

• Device
  ‣ Collection of Sensors and Actuators
  ‣ Multi-channel

• Device Profile
  ‣ Various attributes
  ‣ IP, Location, etc.

• Communication with VPDS
  ‣ Device initiated or VPDS initiated
  ‣ A device can communicate with multiple VPDS
Computed Sensor, Grouped Actuator

- For convenience and simplicity in accessing sensors and actuators
- Expose computed higher level information from a single or multiple sensors
- Assign single semantic meaning to multiple actuators
  ‣ Similar to the concept of “Scenes” in commercial home automation systems
- e.g., In Meeting, Power off the room
Efficient Representation of Sensor Data

- Storing individual samples
  - Inefficient disk space and query processing time
- Inspired by SigSeg in MIT’s XStream
- WaveSegs: non-overlapping windows of sensor stream with metadata
- Support diverse sampling schemes and sensor attributes

Raw Data Samples

RawDataSamples (timestamp, value) ...

WaveSegments (2000 samples per each)

0 timestamp 2000 50,000

```
{
    "DEVICE_NAME": "Office_Flyport",
    "SENSOR_NAME": "MultiSensor",
    "SENSOR_ID": 1,
    "SAMPLING_INTERVAL": 1,
    "EPOCH_TIME": 1344147449,
    "CHANNELS": [
      {
        "NAME": "Temperature",
        "UNIT": "Celsius",
        "READINGS": [28.1, 28.2, 28.6, 28.5, 28.2...]
      },
      {...}
    ]
}
```

JSON Representation of WaveSeg
SensorAct VPDS

Users

VPDS Owners  SensorAct Users

Brokers

Manages Multiple VPDS

Virtual Personal Device Servers (VPDS)

VM Server hosting Multiple VPDS

Dedicated VPDS (e.g., Home Computers)

Devices

Device 1  Device 2  ...  Device n
SensorAct VPDS

- Per user basis ensuring data ownership
- Guard Rule Engine
  - Protect privacy and security in accessing sensors and actuators
- Tasklet Manager
  - Manage and executes user written application logic
- Profile Manager
  - Manages user and device information
- Database
  - Stores sensor data, guard rules, device profiles.
- APIs
  - Device APIs, User/Broker APIs
SensorAct VPDS

- **Tasklet Manager**: Manage and execute user-written application logic
- **Profile Manager**: Manage user and device information
- **Guard Rule Engine**: Protect privacy and security in accessing sensors and actuators
- **Database**: Store sensor data, guard rules, device profiles
- **APIs**: Device APIs, User/Broker APIs
- **Per user basis ensuring data ownership**
- **Tasklet Manager**: Manage and execute user-written application logic
- **Profile Manager**: Manage user and device information
- **Database**: Store sensor data, guard rules, device profiles.
- **APIs**: Device APIs, User/Broker APIs
SensorAct VPDS

• Per user basis ensuring data ownership

• Guard Rule Engine
  ‣ Protect privacy and security in accessing sensors and actuators

• Tasklet Manager
  ‣ Manage and executes user written application logic

• Profile Manager
  ‣ Manages user and device information

• Database
  ‣ Stores sensor data, guard rules, device profiles.

• APIs
  ‣ Device APIs, User/Broker APIs
SensorAct VPDS

- Per user basis ensuring data ownership
- Guard Rule Engine
  - Protect privacy and security in accessing sensors and actuators
- Tasklet Manager
  - Manage and executes user written application logic
- Profile Manager
  - Manages user and device information
- Database
  - Stores sensor data, guard rules, device profiles.
- APIs
  - Device APIs, User/Broker APIs
SensorAct VPDS

- Per user basis ensuring data ownership
- Guard Rule Engine
  - Protect privacy and security in accessing sensors and actuators
- Tasklet Manager
  - Manage and executes user written application logic
- Profile Manager
  - Manages user and device information
- Database
  - Stores sensor data, guard rules, device profiles.
- APIs
  - Device APIs, User/Broker APIs
SensorAct VPDS

- Per user basis ensuring data ownership
- Guard Rule Engine
  - Protect privacy and security in accessing sensors and actuators
- Tasklet Manager
  - Manage and executes user written application logic
- Profile Manager
  - Manages user and device information
- Database
  - Stores sensor data, guard rules, device profiles.
- APIs
  - Device APIs, User/Broker APIs
Privacy & Security: Problem

• Traditional Solutions to Privacy
  ‣ All or nothing mechanisms based on user authentication level

• Selective Sharing & Behavioral Privacy
  ‣ Share only what users want with fine-grained control over what, how much, when, where, with whom

  ‣ Not just anonymity: User identity often required by applications

  ‣ Protecting information that can be inferred from raw sensor data
Privacy & Security: Problem

- **Protected Actuation**
  - Protect against unsafe, inadequate control by users
  - Enforcing policies on actuation
  - Examples
    - Too frequent control of A/C or heaters
    - Temperature control outside of permitted range
Privacy & Security: SensorAct Approach

- Guard Rules for Sensors and Actuators
  - Users define necessary rules for sensor data or actuators
  - Fine-grained access control to sensor data based on user identity, location, time, and sensor values.
  - Context-based suppression and data obfuscation
  - Rich conditions to express various context

```
{
  "NAME": "RuleForBob",
  "DESCRIPTION": "Allow bob@SensorAct.edu to access BuildingA data with values ranging from 60 to 100 and collected during July 2012(PDT)",
  "TARGET_OPERATION": "READ",
  "PRIORITY": 1,
  "CONDITION": "USER.email == bob@SensorAct.edu && LOCATION_TAG == BuildingA && TIME >= 1341126000 && TIME < 1343804400 && VALUE >= 60 && VALUE <= 100",
  "ACTION": "ALLOW"
}
```
Lightweight Tasking Framework

- Traditional Query Interface
  - Application control logic resides outside framework
  - Latency in actuation: heavy data traffic

- Lightweight Tasking Framework
  - Closes the control loop inside the framework
  - Enables audit of what information leaves the framework
Lightweight Tasking Framework

- Various Task Scheduling
  - One-shot
  - Periodic
  - Event driven
  - Periodic and event driven

**Tasklet Request**

```json
{
  "NAME": "Monitor_AC",
  "PARAMS": {
    "T1": "Mickey:Room1:Tempr:1",
    "A1": "Mickey:Room1:AC:1",
    "MINS": 5,
    "LIMIT": 30
  }
}
```

**Tasklet Example**

```lua
-- Reads sensor readings and
-- actuate appliance accordingly

-- epoc MINS minutes before
epocNmin = os.time() - (60*MINS)

-- read MINS minutes avg value
avgTr = VPDS:readAvg(T1, epocNmin)

-- Check and turn ON
if avgTr > LIMIT then
  VPDS:write(A1, VPDS:TURNON)
end
```
SensorAct Brokers

Users

VPDS Owners

SensorAct Users

Brokers

Manages Multiple VPDS

Virtual Personal Device Servers (VPDS)

VM Server hosting Multiple VPDS

Dedicated VPDS (e.g., Home Computers)

Devices

Device 1

Device 2

...
SensorAct Brokers

- VPDS is “personal” data store. Need coordination when sharing.

- Mediators b/w users/applications and VPDS.

- User registration/authentication, discovering VPDS

- VPDS takes responsibility of enforcing privacy and security of data
Implementation

- RESTful APIs
- Java - Play Framework
- MongoDB
- Quartz
- Lua
- Web 2.0
- Open source

https://github.com/iiitd-ucla-pc3
Preliminary Microbenchmark

• Simulated our largest deployment (400 dorm rooms)

• On a Laptop (2.3 GHz Intel i7, 8GB RAM)

Data Collection

<table>
<thead>
<tr>
<th># Devices</th>
<th># Channels</th>
<th>Sampling Rate</th>
<th>Publish Rate</th>
<th>CPU</th>
<th>RAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>10</td>
<td>1 Hz</td>
<td>Every 10 secs</td>
<td>14.6%</td>
<td>3.7%</td>
</tr>
</tbody>
</table>

Query Processing

<table>
<thead>
<tr>
<th>Querier</th>
<th># WaveSegs</th>
<th># Guard Rules</th>
<th>Processing Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>User</td>
<td>90 (10 readings each)</td>
<td>3</td>
<td>3.3 secs</td>
</tr>
<tr>
<td>Owner</td>
<td></td>
<td>0</td>
<td>11 ms</td>
</tr>
</tbody>
</table>
Ongoing Deployment @ IIIT-Delhi

- 400+ student dorm rooms
- Temperature, motion, light and door status
- Smart electricity/water meter across the campus
- Integrates with commercial HVAC systems
Ongoing Deployment @ UCLA

- Wet & Dry Lab deployment
  - Main panel, circuit, outlet level electricity
  - Meter & outlet level water
  - Occupancy
  - Ambient (temperature, light, and pressure)

- Residential deployment
  - Main panel, circuits, outlets
  - Main water
Ongoing Deployment @ IBM

- SoftGreen Testbed
  - Occupancy detection using existing soft sensors

- Software service collects context source status
  - Wi-Fi, Ethernet, CPU
  - IM status, online calendar

- 100+ volunteers

- For ground truth
  - 70+ readers
  - Temperature, motion and light sensors
  - 802.15.4 tags for identity
Conclusion & Future Work

• Experiences from isolated building and campus to international testbed across organizations
• System need to be more responsible
  › A Tiered Distributed Architecture, Sensor and Actuator Guard Rules, Lightweight Tasking framework
• Open to public, work in progress
  › On-going deployment
  › Naming and resource discovery
  › Guard Rules with behavioral privacy
  › Seamless integration of devices
  › Federated Brokers
  › Usability Study
Thank You