Concept and Design of a Cyber-Physical System for Smart Buildings

Lucas Kögel, Faculty of Computer Science, Augsburg University of Applied Sciences

***Abstract*—The possibility to use a cyber-physical system (CPS) for the communication between the distributed sensors and actuators of a building is analyzed. The designed system has the capability to use measured information from the sensors to control the components of the building via its actuators. To interpret the information from several sensors and react afterwards with a suitable action, the system uses complex event processing (CEP). The concept contains the idea to use a software agent for each job, like the complex event processing, read information from sensors or communicate with actuators and to interact with humans.**

***Index Terms*— Complex Event Processing (CEP), Cyber-Physical System (CPS), Smart Building, Software Engineering and Software Technologies**

I. INTRODUCTION

The little keyword "smart" already entered our life, there are smart phones everywhere, smart watches slowly spreading and smart cars getting off the starting blocks. The advertisement is full of smart home technology, explaining on our way home we can start the heating via a smart phone or close the windows, if we forgot them. But what if our home would be smart enough to do these things autonomously? There would be no need to do this by ourselves. At the moment our buildings aren't smart enough to do so, but we have the technologies to achieve this.

Existing technologies like cyber-physical systems, smart buildings, complex event processing and software agents are used to create a concept and design a system for smart buildings to get them smart enough to act autonomic.

First of all the used technologies are illustrated, then they are combined to design a cyber-physical system for smart buildings. The architecture is outlined afterwards, followed by some use cases and the reference project CyPhREE.

II. TECHNOLOGIES

Initially the used technologies for the designed system are described. These are cyber-physical systems, smart buildings, complex event processing and software agents, starting with the cyber-physical system.

A. Cyber-Physical System

A system which interacts with humans is a cyber-physical system (CPS). It extends the physical world trough computing power, by processing information collected in the physical world and affect it by controlling actuators. [1]

The distributed components of a CPS are communicating with each other, to process information or execute tasks. The communication is network-based and various protocols can be used.

Because a cyber-physical system uses information from the physical world to process and control actuators, a smart building is such a good scope of application. Before further elaborating that, an introduction to smart buildings is needed.

B. Smart Building

A smart building measures information with the help of sensors in the building, e.g. the temperature of a room or the state of a window (opened or closed). Only if the building has the ability to get such information, it can get smart.

An actuator for example can be used to open a window or to increase the temperature of the heating. A smart building should use them to get even smarter.

A really smart building should increase the heating via his actuator on the heating, if the sensor on the solar collector indicates a high performance. A sensor like this produces much information, so buildings with many sensors will generate a high amount of information. All these information have to be processed, complex event processing can do that job.

C. Complex Event Processing (CEP)

The information from one sensor is called an event, for example the event could hold a timestamp, the name of the sensor and the measured temperature. A complex event processing engine can process many events per second, for example, the CEP engine Esper can process 500 000 events per second [2]. Furthermore, these engines can analyse complex coherences of sensor events. As an example use case, if a human opens the window the engine will get this information as an event and it will know the low temperature outside from a temperature sensor. Now the engine process these information and will generate a new (more complex) event, which will stop heating the room with the open window.

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Lucas Kögel is with the Faculty of Computer Science, Augsburg University of Applied Sciences, Bavaria, Augsburg 86161, Germany (e-mail: lucas.koegel@hs-augsburg.de).

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Complex event processing uses streams to process the events, they will flow from the input stream through the engine and get out on the output stream. There is no need to persist these events, the will be processed if they occur. Only information from events which are historically relevant should be written into a database.

Michael Eckert and Francois Bry wrote in their paper “Complex Event Processing (CEP)” that a sensor network is a typical use case of complex event processing [3]. So the use of it in a cyber-physical system for a smart building is a good idea, because the sensor information itself is worthless, only the combination of information from various sensors let the complex event processing engine recognize the current situation.

After explaining cyber-physical systems, smart buildings and complex event processing and before putting all together only the concept of software agents should be described in more detail in the following section.

D. Software Agents

Software agents are autonomous programs, designed to solve problems. They have clearly defined boundaries and interfaces, receiving input to reach a goal autonomously. They are designed to fulfil a specified purpose for a given input. To reach their goal, they can communicate with other software agents. The communication could be a simple data request or an order to perform an action. [4]

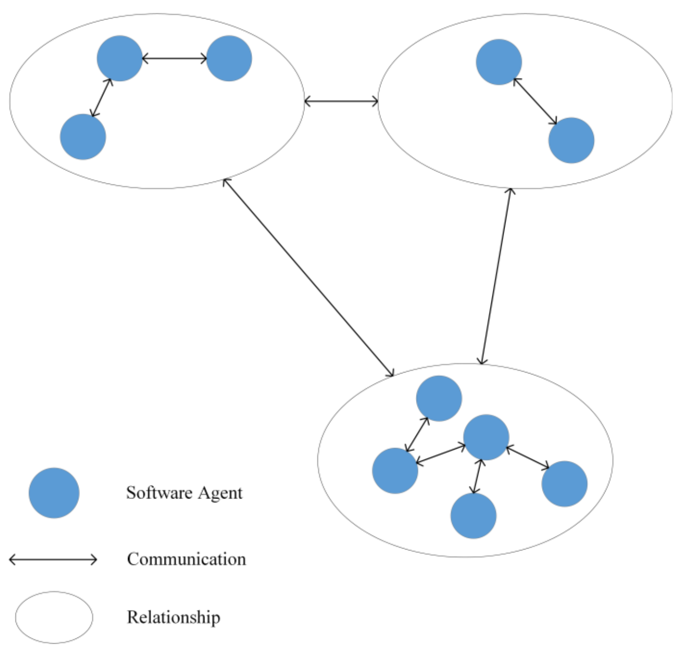

Fig. 1 Software agent communication

A network of software agents, which are communicating with each other, is shown in Fig. 1. The software agents are organized in relationships to solve problems, but they also can communicate with other software agent relationships, if needed.

After outlining cyber-physical systems, smart buildings, complex event processing and software agents, they will be brought together to build a cyber-physical system for smart buildings.

III. PUTTING IT ALL TOGETHER

The research project Industry 4.0 of Prof. Dr.-Ing. Thorsten Schöler at the University of Applied Sciences uses a cyber-physical system with software agents to control a factory. The concept of a CPS for smart buildings is motivated by the architectural ideas of the Industry 4.0 project, so the motivation is that a software agent based cyber-physical system also could be flexible enough to control a smart building. This is outlined in the following section. [5]

A perfect use case for a cyber-physical systems is a smart building, because the CPS can use the sensors and actuators of it to interact with the physical world. Also a smart building needs a system which uses its sensors and actuators to control it and a cyber-physical system will do so. The sensors of the building producing information, they come into the system as a stream of events, each event containing the current state of one sensor. This stream of events has to be processed as fast as possible to react in real time on events which happened in the physical world, like the falling rain on an open skylight. To do so, the CPS must have the capability to process events fast and recognize complex events like the engine Esper, outlined in II.C (Complex Event Processing). Jobs of the cyber-physical system are the complex event processing, read information from sensors or communicate with actuators. Also humans will interact with the building and the job is to process the tasks created by a human. All this jobs are different and must be done simultaneously and autonomously. The designed system uses a software agent for each job, they can work autonomously and all the software agents will act simultaneously. One software agent can do the complex event processing, one can communicate with sensors and actuators and one can run tasks, created by humans. Also a software agent is needed to perform tasks, like to stop the heating of a room or to close all skylights. It knows which actuators must be notified to perform a particular task.

These software agents are outlined in the following section, also the communication between them is shown.

IV. ARCHITECTURE

The purpose of this paper was to design a cyber-physical system for smart buildings, the developed architecture is outlined in the following and shown in Fig. 2 (Communication between the software agents in the designed CPS).

A. M2M Communication – MQTT Server

Starting with step 1 of Fig. 2 the information of the sensors in the smart building arriving the MQTT server over the Message Queue Telemetry Transport (MQTT) protocol. It is used for machine-to-machine (M2M) communication and represent a lightweight implementation of the publish/subscribe pattern. Each MQTT message holds the name of the sensor, the measured information and the timestamp of the measurement. [6] [7]

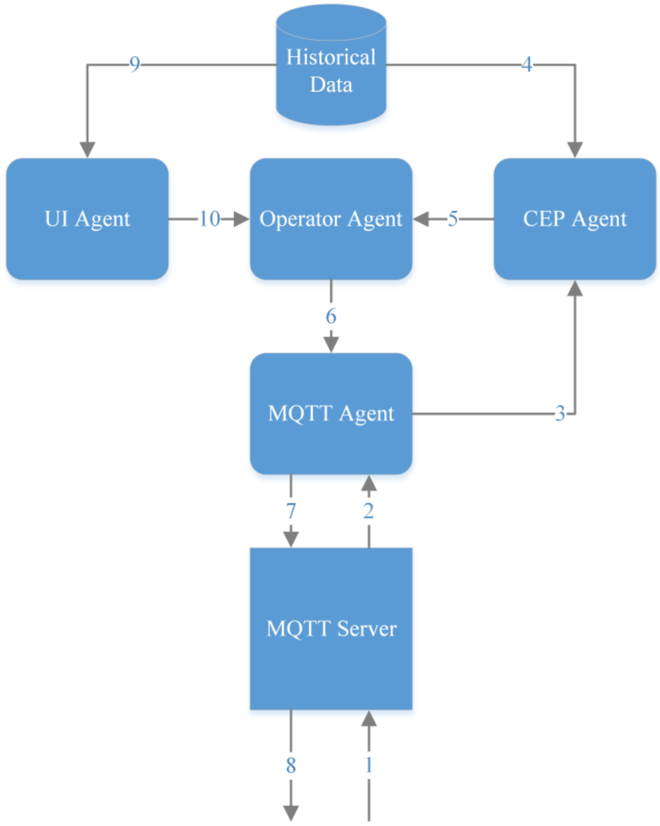

Fig. 2 Communication between the software agents in the designed CPS

B. Receiving Sensor Information – MQTT Agent

The MQTT software agent subscribes to all topics on the MQTT server and will get the published messages, shown in Fig. 2 step 2. It reads timestamp, name and value of the sensor and put this information into a new message for software agents. To process the sensor information, the message will be sent to the CEP software agent (Fig. 2 step 3).

C. Processing Sensor Information – CEP Agent

Rule based decisions will be made by the complex event processing software agent (CEP software agent). It uses the incoming messages with sensor information from the MQTT software agent (Fig. 2 step 3) and persisted sensor information from the Historical Data database (Fig. 2 step 4) to decide what to do. The decision is made by applying rules. If the combination of historical data and incoming sensor information leads the CEP software agent to react, it send a message to the operator software agent to start an operation. This is shown in step 5 of Fig. 2.

D. Performing Operations – Operator Agent

The operator software agent performs all operations affecting the physical world. He knows which actuator has to act to complete an operation. If he receives an operation request, he will send a message to the MQTT software agent containing the information which actuators have to act (Fig. 2 step 6).

E. Instruct Actuators – MQTT Agent

To inform the actuators that they have to act, the MQTT software agent sends a MQTT message to the MQTT server. The software agent will extract all actuators from the message received from the operator software agent and will publish a message for each actuator on the MQTT server (Fig. 2 step 7). The sensors are subscribed to a topic on the MQTT server and so they will get the order to act, shown in step 8 of Fig. 2.

F. Act with Human – UI Agent

The user interface (UI) software agent represents the interface to the human users. It displays the persisted sensor information to the users by reading the historical data, shown in step 9 of Fig. 2. A human in the physical world uses the UI software agent to start an operation in the cyber-physical system. Therefor the software agent sends a message to the operator software agent, which will perform the operation (Fig. 2 step 10).

To clarify the interaction of the software agents in the designed CPS, the next section illustrates some use cases.

V. USE CASES

Two use cases follow, one outlining how the system reacts if it starts to rain and the skylights are open and the second shows the system reacting on high performance of the solar collector.

A. Rain on open skylight

Fig. 3 illustrates the communication between the software agents in the designed cyber-physical system to close the skylight if it starts to rain.

On the MQTT server subscribed MQTT software agent will get the published sensor information of the rain sensor, shown in step 1 and 2 of Fig. 3. The sensor information will be delivered as message to the CEP software agent (step 3 Fig. 3). He will use the recent persisted sensor information about the open skylight and the incoming message about the falling rain, to generate a “close all skylights” operation request for the operator software agent, see step 5 in Fig. 3. Now the operator software agent starts the operation to close all skylights, therefor he needs to know all actuators of skylights in the building. He creates a message containing the actuator names of all the skylights and send it to the MQTT software agent (step 6 Fig. 3). After receiving the message, the software agents starts to extract all the actuator names and publish a message for each on the MQTT server. After the subscribed skylight actuators received the published message, they will close their skylight.

With this reaction on the falling rain, the smart building protects its interior from the rain.

B. Solar collector indicates high performance

Another use case would be the indication of the solar collector for high performance. The sensor information would reach the CEP software agent via MQTT server and MQTT software agent, now the decision to heat or to warm the sanitary water could be made. The CEP software agent can calculate what to do with the high performance of the solar collector, take a decision and request the operation from the operator software agent, which will notify the suitable actuators.

These use cases are only theoretical, but the reference project of this paper will use the developed system to control a real smart building.

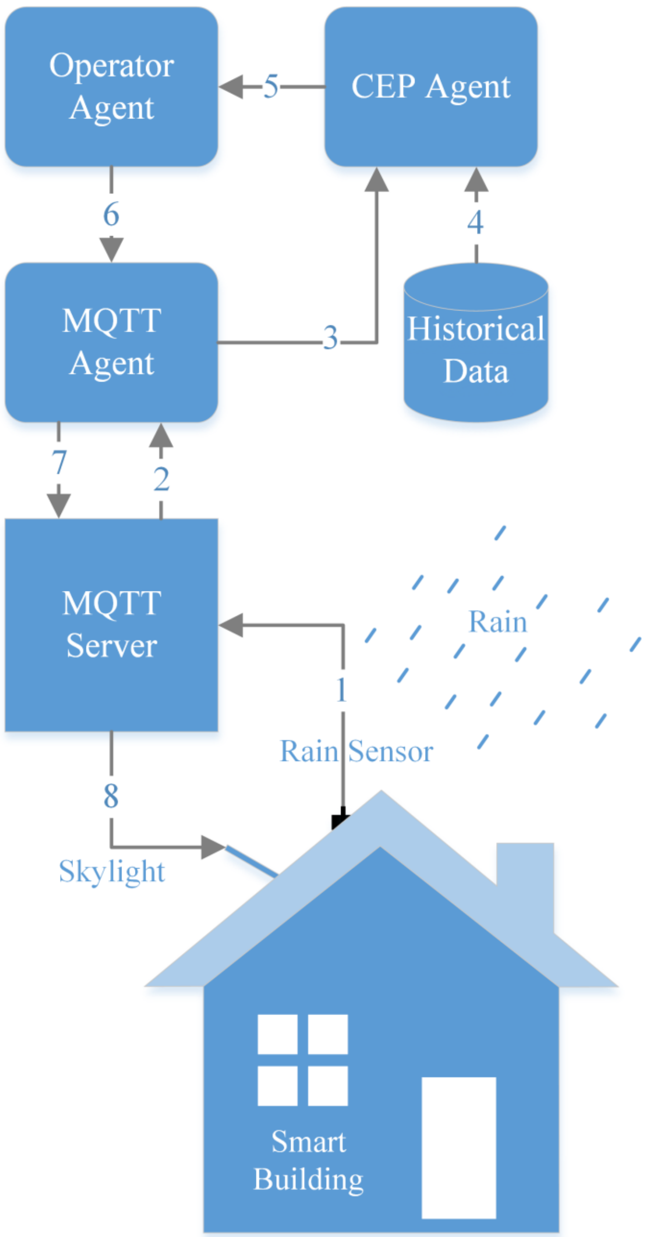

Fig. 3 Communication of the software agents in the designed CPS, if it starts to rain

VI. Reference Project

CyPhREE (Cyber Physical Objects for Renewable Energy) is a project at the University of Applied Sciences Augsburg and a collaboration of the faculties architecture and civil engineering, electrical engineering and computer science. Its purpose is a smart building which is smart enough to control itself. As part of the project a lecture room will get sensors, actuators and a cyber-physical system for smart buildings to control it. The work of this paper is the foundation for the system and its architectural ideas will be used for the development.

In the paper "Complex Event Processing for the Internet of Things and its Applications" a distributed complex event processing engine for Internet of Things is outlined. They designed a preprocessing CEP engine to reduce the bandwidth in communication and the computation load of the backend server. They also wrote a centralized CEP would be limited and inefficient. The designed software agent based CPS can distribute its software agents and the work is spread over them. Preprocessing the sensor information is a good idea and further work will show where it is needed. [8]

VII. Conclusion

With the available technologies, there is the opportunity to develop a real smart building, controlling itself, protecting itself and using energy efficient.

Further works are to implement the designed system and optimize it. Also the CyPhREE project needs to equip the lecture room with sensors and actuators, then the system can be used to control the room. Additionally, the system can be extended with components for the communication between the sensors and actuators and the MQTT Server.

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