IoT and Cloud Technology in Residential and Business premises as Ubiquitous Computing

PETER PAPCUN, ERIK KAJÁTI, IVETA ZOLOTOVÁ
Department of Cybernetics and Artificial Intelligence
Faculty of Electrical Engineering and Informatics
Technical University of Košice
Letná 9, 042 00 Košice
SLOVAK REPUBLIC
peter.papcun@tuke.sk

Abstract: - Nowadays smart products are using local control, which is controlled by remote controllers or applications in smartphones and tablets. People have more and more controllers, who bought these products and devices. Most of these products do not communicate with each other, so user controls every product separately. Internet of Things (IoT) products have a great advantage, this advantage is connectivity to a network Internet. The article describes research and development of intelligent, economical, comfortable, and smart premises for households, workplaces, offices and others business or residential premises. This article describes the realization of intelligent household's scale model, which uses the newest technology for the smart and the comfortable living. Thanks to interconnectivity between IoT products and cloud systems, we want to create ubiquitous computing, at first by our scale model, but then continue with laboratories and other premises. The next advantages of cloud services are data storage by databases and data representation by web pages. Our main aim was to create educational and research model for developing new network and control architecture via modern technology with IoT concept. Various control and communication architectures will be implemented using this model. This aim was solved, and we tried some communication and control architecture through public, private and hybrid cloud described in this article.

Key-Words: - IoT, Cloud, household, control, tablet, smart phone, web-page, Smart Living, Smart House

1 Introduction

Nowadays more and more devices are connecting to the Internet. These devices are not only computers, smartphones, tablets, and televisions but these are fridges, washing machines, or coffee makers. White goods producer has taken IoT concept to their production. In the past, it was a necessity in the industry connects each sensor and actuator to technologic networks, because productions lines have to be controlled by control units, which are connected to this network. Today is effort connects to global network everything, even dust (Smart Dust). This is the world of IoT.

White goods are part of the household. These goods have to be controlled. If you buy IoT goods, you want services from these goods. The best place for services, control, and manage is a cloud. Producers have own clouds solutions on their servers (private cloud). We use public cloud in our solution specifically Microsoft Azure. When a customer wants to use an own private cloud, this cloud has to be in a customer household (for example Raspberry Pi with minimal energy consumption).

In today's times, people have possibilities buying intelligent products (Smart Home, Smart Living) to the household as intelligent bulbs, switches, sockets, and many other products. These products are on the market through previous research, which was running last years. Products use local control via the remote controller or the smartphone. Count of these controllers raises in the household of people, which buying intelligent products (remote controllers, applications in smartphones, tablets, etc.). Mostly these controllers do not communicate with each other, so user controls every type of products separately.

The idea of IoT is interconnectivity. Not only people will be able to communicate with IoT products, but IoT products will be able to communicate with each other. People will be supervisors of their IoT products and households via web applications with one smartphone or one tablet.

Our solution used mainly remote control using cloud systems and cloud computing in this research and development. IoT products can communicate with each other. Local control is not necessary, the product can be control by cloud technology and users do not need the local controller. We use the IoT solution to connect products in the house to the Internet. So, we designed products (things) for house connectable to the Internet only with the home WiFi router, which have every average household.

One of the frameworks for cloud-based smart home was defined by [23] with three main layers: an infrastructure layer, a platform layer, and a service layer. Our solution built all these layers for three different cloud architecture (private, public, and hybrid) described in [24]. Layers from [23] in our solution:

- infrastructure layer: scale household model with sensors, actuators, and controllers,
- platform layer: Windows 10 IoT core or program in EtherDue,
- service layer: Services for household control.

Many research groups ([25], [26], …) are solving IoT gateways for communication with cloud systems. These gateways are very important for this solution. Our research group are also solving this problem, what can be seen in [6], [7], and [22].

IoT products with an own controller or with the cloud control make ubiquitous computing. These IoT products have to be indexing [16], this indexing necessary for our solution.

2 Internet of Things and Cloud

According to studies, it is expected that in the next four years, the average household will have 50 things (products) connected to the Internet. This expectation is followed with increasing number of nodes connected to the Internet. In 2010, 12.5 billion ($12.5x10^9$) devices were connected to the Internet and this number continues to grow (according to [14], [21]). It is not except that this trend will stop.

Today, average family (household in Europe and North America) has two laptops, one computer, two televisions, two set-top boxes, three smartphones, and two tablets connected to the Internet. That is mean 12 IoT products. Approximately 9 devices were connected to the Internet in UK household in 2015 according to [15]. In next three years, people change their white goods for IoT white goods, because the price of these goods will be same as classical goods today. Average European household will have more than 30 IoT products. By 2020, people will connect to the Internet other things as thermostats, boilers, lights, tea tables, kitchen countertops, electrical sockets, etc. That is more than 50 IoT products or devices.

According to our assumption will overcome the mentioned study. We want to contribute to the development of these products (things) connected to the Internet.

The trend to the future is Internet of Things (IoT). The aim of IoT is to connect to global network Internet as many things (products) as it is possible. We want to develop household with many elements connected to the Internet through the remote control on the cloud system. Certain parts of mentioned research and development are described in this article.

IoT is a network of physical objects (things) connected to the Internet. These physical objects have to consist of controller with communication module and software. Nowadays, people have 12 IoT products at home in next few years it will be 50 products. Every of this product has a controller, that is mean computing will be ubiquitous. But we see ubiquitous computing in an even wider sense of interconnectivity, it is described below. IoT world is the way for ubiquitous computing. Interesting opinion has [17].

Cloud technology and IoT (Fig.1) belong to the foremost research and development in IT area in the world. The Computing power of servers and cloud systems continues to grow and services prices are decreasing. Cloud system (cloud computing) is future.

Fig. 1 IoT products connected to cloud [12]

One of our aims is that people have not to buy smart technologies with computing and control units. Smart device will be able to connect to home network and cloud will take care of the control. We use the latest features of cloud systems for this remote control. Specifically, we use cloud possibilities from company Microsoft (Microsoft Azure).

Cloud providers offer services for IoT products connectivity, web application, mobile application, databases, real-time running applications, etc. All of these services will be useful for our solution:

- IoT products connectivity for device interconnect,
- the web and mobile applications for an interface between user and IoT products,
- databases for storage information,
- real time running applications for household control.

We are at the beginning of a new technological revolution: an era where thousands of hitherto disparate and unrelated devices will become connected and able to share information via cloud-based services. This type of interaction will ultimately be made possible through hundreds and thousands of connected sensors, actuators and monitoring devices attached to physical objects, or otherwise embedded into the fabric of buildings, or simply dispersed within the ambient environment. [12]

Inputs and outputs of mentioned sensors and actuators will make large amounts of data, what is opening options for Big Data and Data Mining.

3 Model of Household

On our laboratory, we are working on IoT household controlled by cloud systems. We are building a scale model of the household.

This model is built from extruded polystyrene, roof and windows are from plexiglass, doors are wooden, and a floor is made of laminate. When we implement all cables, sensors, and actuators to polystyrene and laminate, the model will be plastered with a whole technological process (cement construction mortar, fiberglass mesh, plaster). The basic frame of the model made of polystyrene is in figure Fig.2.

IoT products will be installed on this model. These products will be connected to cloud Microsoft Azure. Products control will run on this cloud as a service. If all components are connected to one platform, then they have the chance and the ability to communicate with each other, this communication is absenting at today's smart products mostly. Communication between things and products brings new possibilities for comfortable living. For example, coffeemaker does not turn on at a certain preset time, but when user parks his car, eventually user comes home.

Fig.2 Basic frame of intelligent household model

During the design of IoT products will be an emphasis on easy installation and the capacity of the network in the household. In the average household, a home router can connect 254 nodes (elements, products, things) by wireless network WiFi and by Ethernet cable. Nowadays, home routers use IPv4 addressing with 24 bits of network prefix for an own private network, therefore is the limitation to 254 nodes. In future, IPv6 addressing will be very important for IoT world, because IPv4 can address maximally 4 billion nodes. This is 3 times less than was connected devices in 2010. IPv4 still works only through NAT (Network Address Translation).

In addition to this, we will heed to healthcare through the intelligent house. Healthcare will be ensured by controlling the atmosphere in the rooms or follow users' behavior in an apartment by a camera system and microphones (fall, scream, etc.) and based on the inputs to the system call for help [19]. Of course in the house will be a large number of sensors and actuators, which will be specified to other activity, but they will be able to participate in healthcare.

After successful completion of the model, the created model can be used in the education of IoT Systems, Cloud Solutions, Architecture of Industrial Information Systems, Single-chip Microcomputer, Computer Systems in Control and other studies courses dealing with the latest technology.

Already in the past in our department, we were conducted research and development of intelligent and energy-efficient living spaces (household, office, etc.). It was a local control of house model with visualization. Research and development of this model are described in [1], [2]. In addition, this model was used in the process of education and teaching. Therefore, it is the large assumption, that the new model will be used also for these purposes. Mentioned model has worked on other technologies than the new model, which we are describing on this contribution.

Research, development, and build of this new model of the household are a project. We named this project. Its name is CASTLE (**C**omfortable **a**nd **S**mar**t** **L**iving **E**xpanded). This project is national (Slovak) project.

4 Phases of the Project

This project is divided into four phases. The first phase designs and models house with a necessary electrical installation. The second phase builds the model of the house with electrical installation. The third phase realizes temperature and light control by cloud technology from Microsoft Azure. The last phase realizes control of other elements via cloud system (for example RFID, camera system, etc.).

4.1 The First Phase

This phase designs the used building materials, cabling, basic installed elements, ground plan, wiring project for the model of the house. Besides, the first phase creates a simulation model for a physical model of the household.

The first phase is completed. Building materials are extruded polystyrene, plexiglass, wood, laminate, cement construction mortar, fiberglass mesh and plaster. The use of the mentioned materials is described above. Model of the house uses 12V and 24V DC electrical installations because we use actuators and sensors with mentioned voltage. Also, 220 V AC is dangerous for the scale model of the house. Basic installed elements are intended for thermal and light systems (temperature sensors, peltiers, blinds with drive, LEDs, etc.).

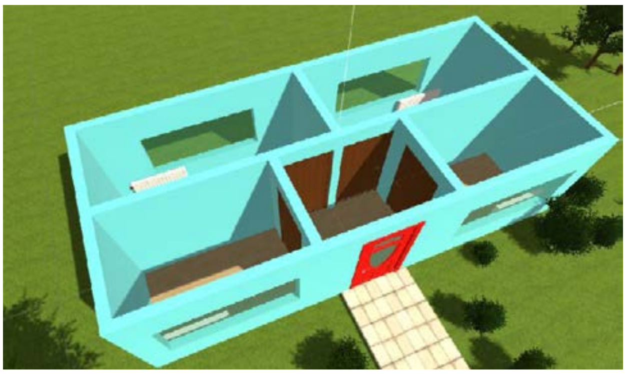

Fig.3 Simulation model of household

The simulation model is programmed in program language C# through environment Unity. We can simulate a thermal system, through the simulation model of the household. Algorithm of temperature control is programmed and simulated here. Simulation model includes thermal throughput of polystyrene, wood, and plexiglass. We use fuzzy regulation for temperature control.

This simulation model can be used also for layout design of sensors and actuators. The simulation model of household in Unity is in figure Fig.3.

4.2 The Second Phase

During the second phase is built the model of the household. The procedure is described in the description of the model. The basic frame of the intelligent household model is in figure Fig. 3. Laminate flooring is elevated from the bottom to add more sensors and actuators. Realization of the switchboard is included to this phase. Switchboard for our model is in figure Fig.4.

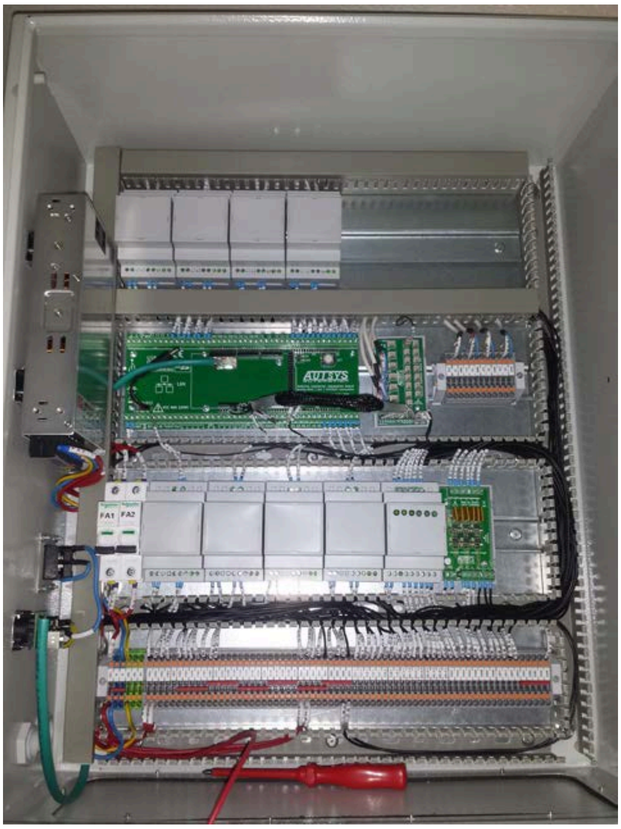

Fig.4 Switchboard

The control unit of the switchboard is EtherDue. Its place is in the socket where you can see Ethernet and power cable (the second row of electrical elements on figure Fig.4). EtherDue (Fig.5) is a device with the same architecture as Arduino Due with Ethernet shield, but EtherDue has integrated Ethernet interface.

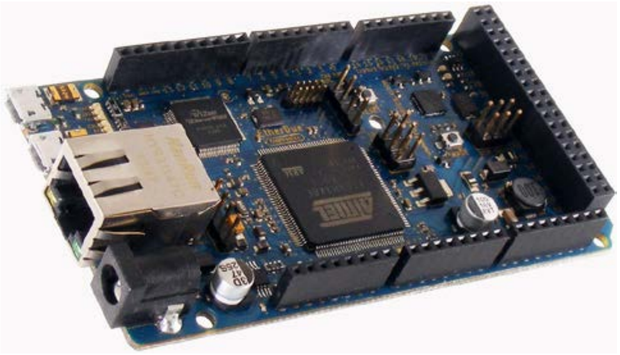

Fig.5 EtherDue

Sensors and actuators for thermal and light systems was developed during this phase. The thermal system consists of temperature sensors, air condition. Scale model of air condition (Fig.6) is made from peltier, passive and active coolers. Peltier is between two passive coolers (heatsinks). Heat transfer ensures active coolers (fans). The light system consists of LED strip, blinds, and photo-resistors.

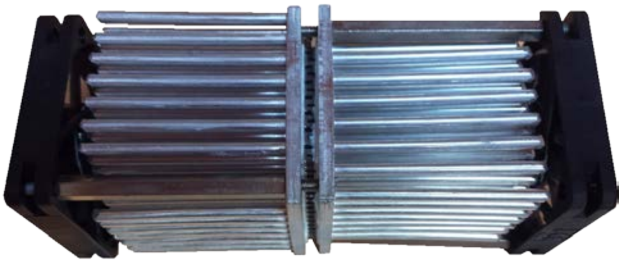

Fig.6 Air condition for our model

We developed PCB (printed circuit board) with the socket for EtherDue (Fig. 4, Fig. 7), this socket is fully compatible with Arduino. PCB is connected via copper cables with others our PCBs and connectors blocks. The PCB was created for better handling and connecting cables to the controller (EtherDue or Arduino).

Fig.7 PCB with socket for EtherDue

H-bridge Controller (Fig. 8) is PCB developed for thermoregulation (peltier) and regulation of blinds (motors). This PCB allows connecting actuators to the controller with power supply from 12 to 40V and maximum current 33 A. H-Bridge Controller is placed in a standardized box for the switchboard.

Fig.8 H-Bridge Controller

MOSFET power stage (Fig. 9) with 6 channels is developed for LED strip and fans on air condition. The maximum supply voltage is 30V DC and current consumption 5A. Controller is placed in the same standardized box for the switchboard.

Fig.9 MOSFET power stage

Mentioned PCBs can be used on others devices with power supply from 12 to 24 Volts. During this phase was developed many others PCBs and improvements of sensors and actuators. Two power supply is installed in the switchboard, the first supplies 12V, and the second supplies 24V. The physical model is shown in figure Fig. 10.

Fig.10 Physical model CASTLE

4.3 The Third Phase

When we have constructed the model with sensors, actuators, switchboard and we have simulated the thermal system, we can program this control to the cloud system. This control is programmed as a service through Microsoft Azure. Using the same service is also controlled lighting system. This phase has many options of realization. These options are described in the next chapter named *Models of Control*. This service will be enriched by control of IoT products developed in the fourth phase.

4.4 The Fourth Phase

At this phase will be designed other IoT products, which will use in the project. Priority will be to search existing IoT components for household, but their number is still low, so this design will be extended.

The extended part of the design will propose devices individually from appearance design, via electronic proposal, to material design. Finally, all proposals will be implemented and installed on the model of the household. These devices will be connected to the cloud from Microsoft Azure. Communication protocols will be set and programmed. Regulation and control will be programmed for designed IoT devices (products, things). Creating a web HMI (human -machine interface) environment for the user will be also necessary (in addition to the necessary services for control). This web page (HMI) will be part of the cloud system creation. For a long time, HMI is not just a matter of industry. Search, design, and programming of possible interactions between elements in the home will be part of this phase. At this phase, we are still working. Many sensor and actuators make possibilities for multi-agent systems with interactions.

5 Models of Control

The first idea was to keep the whole control of house on the cloud. This model of control works, but household becomes dependent on the Internet connection. If the provider can guarantee non-stop connection to the Internet, then control can stay on the cloud system.

In 1961, John McCarthy defines utility computing (nowadays cloud computing) and he compares this utility computing with electricity and water. His idea was that in the future we will buy computing power as electricity or water in the home. [3]

With this mentality and after few years, people can be dependent on the remote cloud-based systems and the Internet, as now on electricity and water. So we decided not to leave everything to the remote and public cloud and we come with three options:

- control and HMI through the public cloud,
- control and HMI through the private cloud,
- control and HMI through the hybrid cloud.

Previously, often was mentioned service for control in this paper. These services can be named CaaS (Control as a Service). Classically, cloud services are divided to:

- IaaS (Infrastructure as a service),
- PaaS (Platform as a service),
- SaaS (Software as a service).

CaaS is software as a service, which is specialized for control. CaaS is not defined as a basic group of cloud services, yet. We are not the first, who use term CaaS, before us use this term [4], [5]. Imagine an environment where IoT devices perform only basic computing and cloud services as the CaaS perform control and manage interconnection between IoT devices. In our opinion, this is ubiquitous computing in the wider sense. Ordinary users will feel ubiquitous computing, but they do not know where ubiquitous computing is. They do not be interested where it is, because it will be ubiquitous.

5.1 Control and HMI through Public Cloud

We use services of Microsoft Azure for control and HMI through the public cloud. Microsoft Azure has special services for IoT products. These services are IoT Hub, Event Hubs, Stream Analytics, etc. There are other companies offering similar services, for example, IBM with IBM Bluemix, Amazon with Amazon Web Services.

We have implemented three types of architecture:

- Raspberry Pi as IoT gateway with operating system Windows 10 IoT core,
- EtherDue communicates by HTML requests with the cloud system,
- EtherDue communicates by MQTT or AMQP with the cloud system.

The first architecture was presented at Microsoft IoT Hackathon by our research group. All IoT devices are connected to Raspberry Pi by Ethernet, WiFi, Bluetooth, and others interfaces. Raspberry Pi sends all information from sensors to public cloud by MQTT protocol via service named Event Hub. Our solution uses Microsoft Azure as public cloud. This information is transformed by service Stream Analytics. Then it is stored in the NoSQL database, and presented by the web page (HMI). The last step sends information to devices (actuators) to take action. Described scenario is shown in Fig. 11.

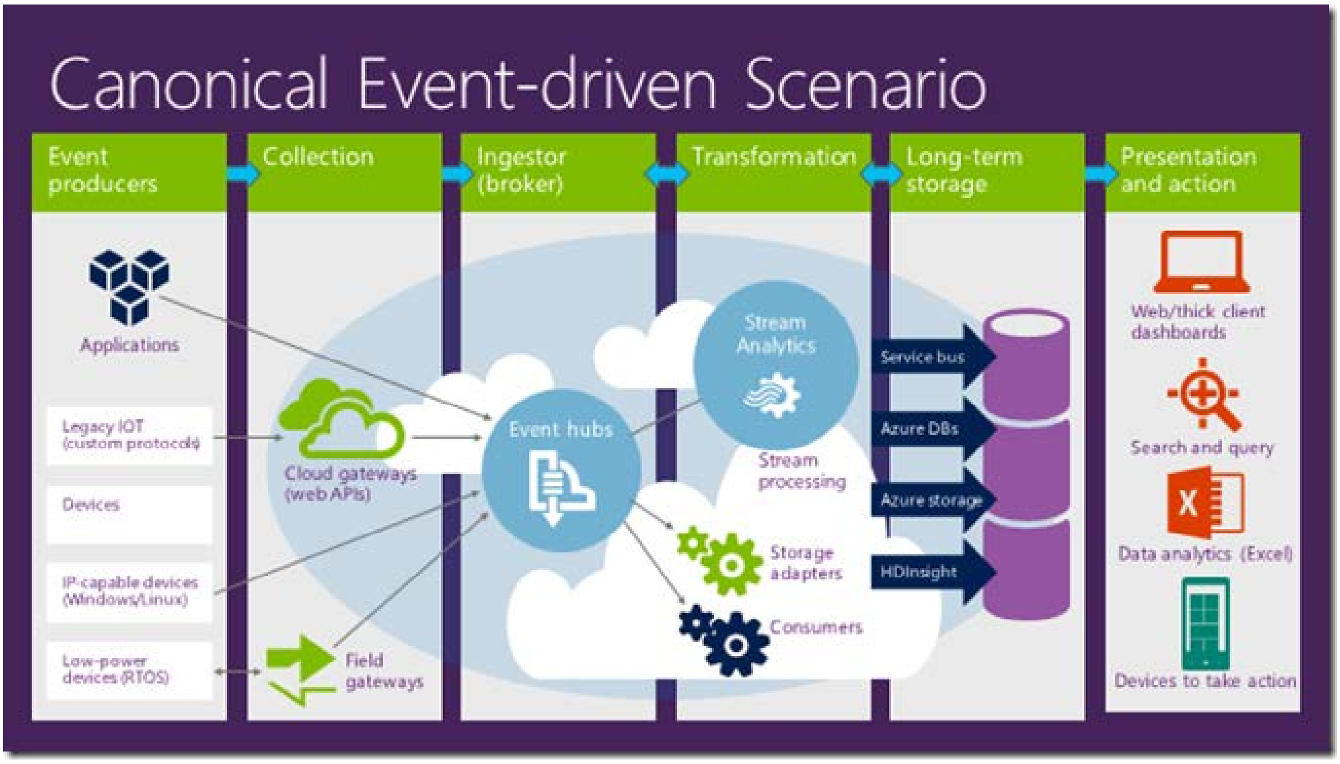

Fig.11 Canonical Event-driven Scenario [13]

The second architecture is using on our household model. EtherDue collects data from all devices in the house. This data is sent to the public cloud as an HTTP request. Cloud this request evaluate: store date to the database, dynamically change HMI web page, and calculate control variables for actuators in the house. These variables are sent back to EtherDue as an HTTP response.

The last architecture is similar to the first architecture, but EtherDue is used without Windows 10 IoT Core. The architecture use MQTT or AMQP protocol, Event hubs (for example IoT hub), Stream Analytics, etc. (Fig. 11). This last architecture is the best according to latency. We used the second architecture, because this model is used for education, and RestAPI is a more general solution than Events hubs from Microsoft.

In this solution, web page (HMI) and control algorithms are running on the public and remote cloud system. All information from sensors is sending to cloud and all information to actuators is receiving from the cloud.

This solution is dependent on the Internet connectivity fully. Part of HMI (light control) can be seen in figure Fig. 12.

In this case, the provider of cloud services is responsible for security. Safety is in the hands of an integrator (or user) that installs IoT products, programs control and HMI web page for the household.

5.2 Control and HMI through Private Cloud

User (or integrator) can build own server, which will control user's household. If the user uses classical server or personal computer, then the solution is not economical because a classical computer has average power consumption 200 W (from 70 W to 500 W), that is mean 1700 kWh per year. If the user uses a notebook as a server, then average power consumption is 50 W that is mean 425 kWh per year. But when is used Raspberry Pi (Fig. 13), then power consumption falls to 2 W that is mean 18 kWh per year.

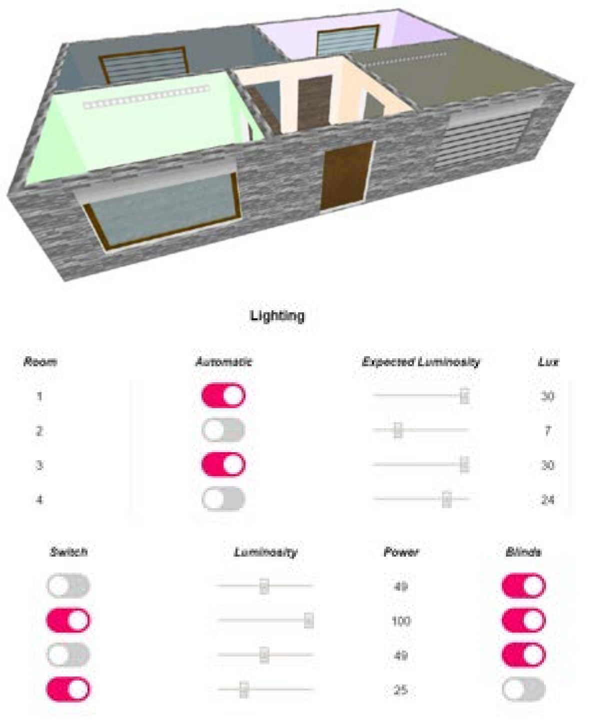

Fig.12 Part of web page (HMI)

When we want to use the home server, we need public and static IP address. Most Internet providers use dynamic or private IP address because they want to provide the Internet to many people with small address space.

Fig.13 Raspberry Pi model 3

If we use the private address, then control will function only in local home network and the user can not control house by HMI outside of this network. If we use the dynamic address, then we have to know our actual address every time, when we want to connect to our house. If we have static and public IP address, we can implement our solution of control by the private cloud. Control algorithms and HMI web page are programmed on Raspberry Pi and every IoT product has to communicate with Raspberry Pi. Raspberry Pi is the web server and the household controller at the same time. This solution is not dependent on the Internet connectivity. When Internet connectivity is lost, the user can not connect to HMI outside the home network, but control is running.

Security and safety are in charge integrator in this case.

5.3 Control and HMI through Hybrid Cloud

This model has distributed control algorithms and HMI web page. Control algorithms are running on the private cloud and HMI is running on the public cloud. Static and public IP address is not important because communication between clouds provides HTTP requests. Private cloud is an HTTP client, which is sending requests to HTTP server (public cloud) every sample time.

Controller (private cloud provides CaaS) may not be the computer, but the controller can be Arduino with Ethernet or WiFi shield, EtherDue or any single-chip microcontroller with Ethernet or WiFi. HMI web page is running on the public cloud and the user can monitor and set household from everywhere because these clouds communicate between each other.

Safety is in charge integrator as in previous options. In this case, the provider of web services is responsible for security.

The first and the third *model of control* can use IoT gateway for distribution of data, and SOA (service oriented architecture) for data acquisition and data processing. Our research group is researching and developing these technologies, what can be seen in [6], [7], and [22].

6 Research and development impacts

Thanks to this project occur development in two directions immediately: the development of IoT products and the development of CaaS for households. The web server is running on the cloud, thanks to this web can be controlled and set requirements of the household. So the user can control the particular thing at home on a tablet, laptop, smartphone or other devices which can display the web page. Such control would not be necessary to develop separately for each household.

It could develop only one service that could be joint to any household.

Mentioned process would reduce the cost of production of these smart devices and the development of control would not be directed to a specific household. A control algorithm could be used for any household.

6.1 Benefits

Results can be divided into three groups:

1. technical or hardware solution,
2. software solution,
3. methodic.

The technical solution includes a functional model of the smart home with all installed IoT elements connected to the global Internet. This smart home with IoT elements are controlled from a web browser and it is regulated and controlled remotely. The technical solution also includes various IoT elements, which was developed under the project CASTLE. Until that time, it was developed:

- thermo-regulatory elements made of peltier, heatsink, and fan,
- the system of temperature sensors,
- light system: the system of actuators (blinds, LED lights) and sensors (photoresistors),
- switchboard.

Software solution includes:

- individual firmware for IoT products,
- remote control and regulation algorithms for IoT products,
- web HMI environment running on the same platform as control and regulation of IoT products,
- algorithms of interaction between IoT products.

Methodic was mentioned in chapter *Models of Control*, where was described control and HMI through private, public and hybrid clouds.

7 Conclusion

This paper defined three models of control for IoT residential and business premises and described implementation methodic. Also, our research group built scale household model using described methodic.

The project will benefit in the social sphere, whether it will be a comfortable living, intuitive systems or price reductions of smart products. This product will benefit the production sphere since in this area may find inspiration. Also, a platform of application developed during this project foresees the significant potential for commercial use.

Project CASTLE (model and concept of system creation) has a high envisages the use in the education of the latest technology. Specifically, the education of IoT Systems, Cloud Solutions, Architecture of Industrial Information Systems, Single-chip Microcomputer, Computer Systems in Control and other studies courses dealing with the latest IoT and cloud technology.

After the successful implementation of the project CASTLE, our team wants to continue creating smart IoT rooms (laboratories) at our department. We want to move from a physical model solution to a real solution. In future, this solution can be used in real households, offices, workplaces and others residential or business premises. IoT network itself creates ubiquitous computing, but if it adds interconnection with cloud technology and CaaS, then ubiquitous computing is expanded.

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