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ABSTRACT

In this paper, we present one of the pilot applications of the SYNAISTHISI project, whose goal is to transform a typical meeting room to a "smart meeting room". The SYNAISTHISI platform is used to provide the necessary infrastructure to interconnect heterogeneous devices and services over heterogeneous networks. In the presented case, multiple sensing, processing and actuation units have been developed and deployed. The room's state is continuously monitored and either manually, remotely, or even through automatic processes, decisions are made to control the room lights, cooling, heating, and projector operation. For example, when a meeting is scheduled, the lights and the projector turn on automatically. During the meeting session, environmental measurements (temperature, humidity and ambient light), energy consumption measurements and estimations of the number of people present are collected. Maintaining comfort levels for room occupants is achieved through automatic rule-based decision making. In order to evaluate our approach we follow a qualitative evaluation performed by real-life users of the Smart Room.

1. INTRODUCTION

Recent advances in intelligent computer systems and communications have created the necessary conditions for the networking of a wide variety of heterogeneous devices. This led to the integration of short-range mobile transceivers into everyday life objects and has enabled new forms of communication between objects and even between people and objects. The concept of smart devices, i.e. the inclusion of software, identifiers and networking to devices typically not computerized, led to the "Internet of Things" (IoT) [5].

The main feature of this technology is the integration of heterogeneous sensing and action elements (actuators) in a distributed system which performs different actions based on the information gathered by the sensors combined with the requirements of the particular application. Intelligent information systems enable the processing of multimodal data collected by the sensors, so as to reconcile heterogeneous information and safe conclusions on the facts giving rise to the activation of the necessary actions to address the consequences of these events. Moreover, the availability of new (smart) energy meters allows for real-time monitoring of energy consumption and provides a unique opportunity of using energy more efficiently.

In previous works [4, 3, 2], we presented a novel platform, namely SYNAISTHISI, whose goal was to facilitate the interconnection and coordination of a large set of heterogeneous devices. In this work we will show in detail how to build energy efficient and effective applications and services to end users, on top of SYNAISTHISI, by creating a smart meeting room. Within this room we aim to minimize a) the environmental impact; b) monetary costs; c) user discomfort; d) delays; and e) utilization of resources. The first two requirements can be met by minimizing unnecessary heating or cooling and light usage. User comfort levels are set by international policies, e.g., health and safety standards. Minimizing delays refers to having services available on demand. Lastly, minimizing the utilization of internal resources means that at all times the availability of the system must be maintained at the maximum possible levels and needless usage of resources should be avoided.

In accord with the IoT paradigm, the services we offer are categorized into three distinct types: S–type services consist of the measurements of sensors; P–type services of the processing of those measurements; A–type services actuate the inferred decisions. We focus on keeping comfort levels by providing automation and control of room environment, accordingly. The approach we follow allows for easy reconfiguration of the available resources to augment any appropriately equipped room with state-of-the-art cognitive processes, such as decision making.

In this paper we also present the service hierarchy and decision making component of the current work in detail. Furthermore, we present qualitative results concerning the efficiency of the smart room in terms of end-user satisfaction. Our results are in general in favour of the proposed smart room solution.

The remaining of this paper is structured as follows: In Section 2 we present several past approaches for implementing and managing a smart room, compared to the proposed approach and emphasizing on the novelties of the latter. Section 3 provides a brief description of the SYNAISTHISI platform, which we use to interconnect the required modules to deliver the smart room application. Next, in Section 4 we present the several Sensor, Processing and Actuation services we have implemented and comprise the current functionalities of the room. In Section 5 we present user evaluation results, based on questionnaires filled in by a sample of users of the smart room. Finally, in Section 6, conclusions are drawn and plans for future work are presented.

2. RELATED WORK

In general, previous smart rooms e.g., [12] and [8], aim solely in sensing the environmental state. An application with more advanced capabilities is the one of [15]. It uses audio-visual analysis methods to deliver meeting support functionality, e.g. lecture keywords extraction, person identification, and activity awareness. Previous approaches on audiovisual analysis [1, 11] rely on expensive and specialized hardware, making the installation and usage of the complete system more expensive and less portable.

In contrast to those approaches, the one presented herein, apart from sensing, monitoring, and processing functionality, incorporates actuating features as well, such as light and HVAC control. Moreover, it facilitates the delivery of all the aforementioned features, using either existing, pre-installed equipment, or newly installed low-cost devices. Apart from that, as it has been already mentioned, among our targets is to minimize energy losses and maximize the energy efficiency of the room's resources during scheduled meetings.

As far as decision making is concerned, various approaches have been proposed in the literature [13, 14, 16]. Some of these approaches analyze numerical and statistical context and can learn how to act, leaning on adaptive functions that in most cases are represented by graphs, such as neural networks and probabilistic graphical models. The learning algorithm is actually an optimization method that targets to correct the behavior. Time-varying adaptive functions such as recurrent neural networks [6] have been used in decision-making agents that act in dynamic environments, and in intelligent environments as well [10, 9]. Reinforcement Learning approaches [7], rely on modeling the environment by an observable or partially observable space of states, which is characterized by the available sensory information and aim to find an optimal policy, so as to map (sequences of) states to actions and optimize an evaluation measure of the agent. In our case, the preferences of the room's visitors are expected to be highly dispersed, since it is a room used for many types of meetings. Thus, we choose not to follow a learning approach. By equipping the Decision Maker (DM) with a GUI, we allow the user to provide assessments over the automatic functionality and also to bypass the DM's actions when these are perceived as inappropriate. We show, according to the user experience-based evaluation we have conducted, that the proposed paradigm works in a satisfactory manner.

3. THE SYNAISTHISI PLATFORM

The SYNAISTHISI platform is mainly composed of:

i. a *Message Oriented Middleware* (MOM), which is actually a central message broker running on cloud and accessible from all internet–enabled devices. Its goal is to support inter– and intra–machine communication.
ii. a *REST web server*, whose role is to provide a control layer over the available resources.
iii. a *Resource piping mechanism*, which allows for quick development and deployment of custom applications.

All services communicate by publishing and/or subscribing messages within *topics*, which are equivalent to addresses. Measurements, decisions and commands are encapsulated into messages, based on the protocol standard. Once a message is published on a topic, an additional role of the MOM is to inform and deliver the message to all clients that are subscribed to that topic.

Our MOM of choice uses the MQTT protocol[1]. An MQTT client is running at each of the available sensors, connected to the SYNAISTHISI MOM and listening to messages that trigger the start/stop of each device's activity. This allows for an easy way to send commands to all available sensors simultaneously and without having to worry about their number. Since new sensors can be added with minimal configuration, the goal of scalability is achieved.

[1]http://docs.oasis-open.org/mqtt/mqtt/v3.1.1/mqtt-v3.1.1.html

4. SMART ROOM APPLICATION

In this Section we present a pilot application of the SYNAISTHISI project. A typical meeting room, located at the Institute of Informatics and Telecommunications (IIT), N.C.S.R. "Demokritos" has been transformed into a smart room. We discuss the use case scenario, the implementation and the room's functionality.

4.1 Scenario Description

Our application incorporates sensors (S–type services) and actuators (A–type services), physically installed in the room, as well as processing units (P–type services) running in the cloud. The DM is a P–type service performing decision support operations. It communicates via the SYNAISTHISI platform with several S–, P– and A–type services. It uses measurements of the installed sensors, so as to recognize specific events that occur inside the room, regarding ambience state (temperature, humidity, luminosity), electricity consumption levels, and occupancy. These measurements are temporally aligned by a data fusion module. Then, specific actuations take place, automatically, autonomously and in real time. Their aim is to minimize energy losses, while maintaining certain comfort levels, i.e., improving the overall working environment. This functionality aims to satisfy the needs of the following user-oriented scenario:

> "A meeting is scheduled in the smart meeting room. At the scheduled time, the plugs of this room are automatically activated by turning on the smart plugs. When the first user enters the room, he/she is greeted by a synthetic voice from the speakers, and the lights turn on. Camera sensors estimate the number of people present and ambient sensors measure temperature, humidity, and luminosity. Gas sensors measure air quality for certain types of dangerous gases (e.g. CO_2, CO, etc.) When the meeting is about to start, the projector turns on, the front lights turn off, and a welcome announcement is actuated from the speakers. During the meeting, the DM module takes into account the state of the room sensors and decides if it is required to change the state of cooling/heating devices. When the meeting ends and no people are detected into the room, the lights, the projector and the cooling/heating devices are turned off".

4.2 System Architecture

In Fig. 1 we depict a high-level description of the system architecture. As it can be seen clearly, the DM uses the generated output of all other P–type services, in order to trigger actuations to be realized, each time according to the policy settings. The latter may be configured to minimize energy losses, while maintaining satisfactory comfort levels of the room's occupants. The measurements of the S–type services are processed by the P–type services, fused and fed to the DM module. We should emphasize that every exchange of information (e.g. control arguments, data sharing etc.), is actually performed via the SYNAISTHISI platform.

The data storage module is implemented as a cloud service. In addition, certain A–type services are provided, so

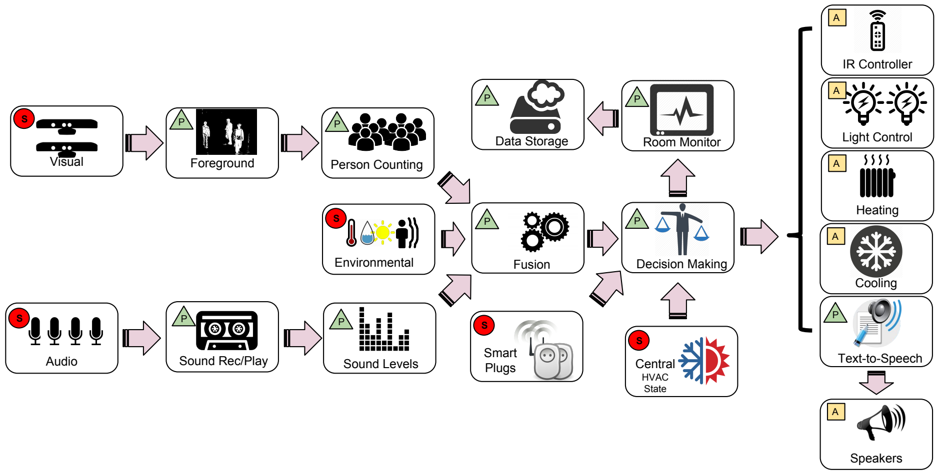

Figure 1: High-level architecture of the smart room application.

that the DM module can control the corresponding resources appropriately i.e., mains plug switches, and infrared remote control modules. Finally, a set of speakers is used for loud announcements or alerts on request from the DM, using a text-to-speech synthesis tool.

4.3 Information Extraction and Processing

In order to extract several real world measurements, we have implemented a set of S–type services. More specifically, we have installed temperature, humidity, luminosity and gas sensors, RGB and depth cameras and microphone arrays. The environmental sensors continuously publish their measurements to SYNAISTHISI. Depth cameras publish on demand raw RGB, depth and audio data. Each of the aforementioned measurements may then be used by any P–type service, registered on the platform.

The implementation of the aforementioned S–type services uses only open source software and low-cost sensors. More specifically the environmental sensors are connected to an Arduino Yun[2] and publish their measurements at appropriate topics, using a compatible MQTT publisher.[3] Cameras have been connected to Raspberry Pis,[4] using Paho[5] in order to publish RGB and depth values. Audio data are captured using GStreamer library[6] and published as raw (byte) at a separate topic for each device. Audio capture can be toggled by publishing appropriate commands and information for the published data can also be retrieved (e.g., number of audio channels, sampling rate, byte format etc.).

The set of P–type services that utilizes the aforementioned measurements is located on the cloud. Each service implements a subscriber to the appropriate topic(s). Currently, the following services have been implemented: a) a Background Subtraction (BS) module that uses the received RGB data and upon processing it estimates the foreground of the scene; b) a Person Counting (PC) module that works on the foreground, detects faces, upper bodies and full bodies and provides an estimation of the people present in the room; c) an Audio-dB (AdB) module that uses raw audio data and publishes sound level measurements in dB; d) an Audio-Playback (AP) module uses raw audio data and after the appropriate and required conversions (e.g. resampling, downmixing etc.), it enables playback of the received data from a sound card; e) an Audio-Recording (AR) module records published raw audio data it to a sound file, using Ogg Vorbis codec,[7] after making the necessary conversions; and f) a Data Fusion (DF) module which subscribes to all topics and is responsible to temporally align all measurements, add the necessary timestamps and create a textual description to be understood by the DM.

The BS and PC modules have been implemented from scratch in C++, using OpenCV.[8] The AdB, AP and AR modules have been implemented using Python GStreamer library. Finally, the DF module has had two implementations, one as a standalone Python script and one as part of the DM. The latter is a Ruby script, intended to work as a redundant secondary backup service.

4.4 Decision Making

As it has already been mentioned, the DM module is the core of the smart room. It is a P–type service, aiming to handle all decision–making tasks. It receives input from the SYNAISTHISI platform by subscribing to topics that publish energy consumption measurements from plugs and environment sensor measurements. Using this information it is able to actuate specific tasks, according to the current needs. More specifically, it is currently able to: a) turn on/off the projector; b) turn on/off the room lights; c) turn on/off heating/cooling; d) speak out announcements and e) enable the alarm. The modules that communicate with the DM are shown in Fig. 1.

A flowchart describing the operation of the DM is illustrated in Fig. 3. The set of rules used by the DM can be viewed in Table 1 The DM has been written in Ruby.

In order for the room user to be able to monitor the room condition and deactivate or activate the DM at will, we have created a web-based dashboard to complement smart room functionality. The dashboard GUI is illustrated in Fig. 2; it has been implemented in Javascript and HTML5/CSS3/

[2]http://www.arduino.cc/en/Main/ArduinoBoardYun
[3]http://knolleary.net/arduino-client-for-mqtt/
[4]https://www.raspberrypi.org/
[5]https://eclipse.org/paho/clients/python/
[6]http://gstreamer.freedesktop.org/
[7]http://www.vorbis.com/
[8]http://opencv.org

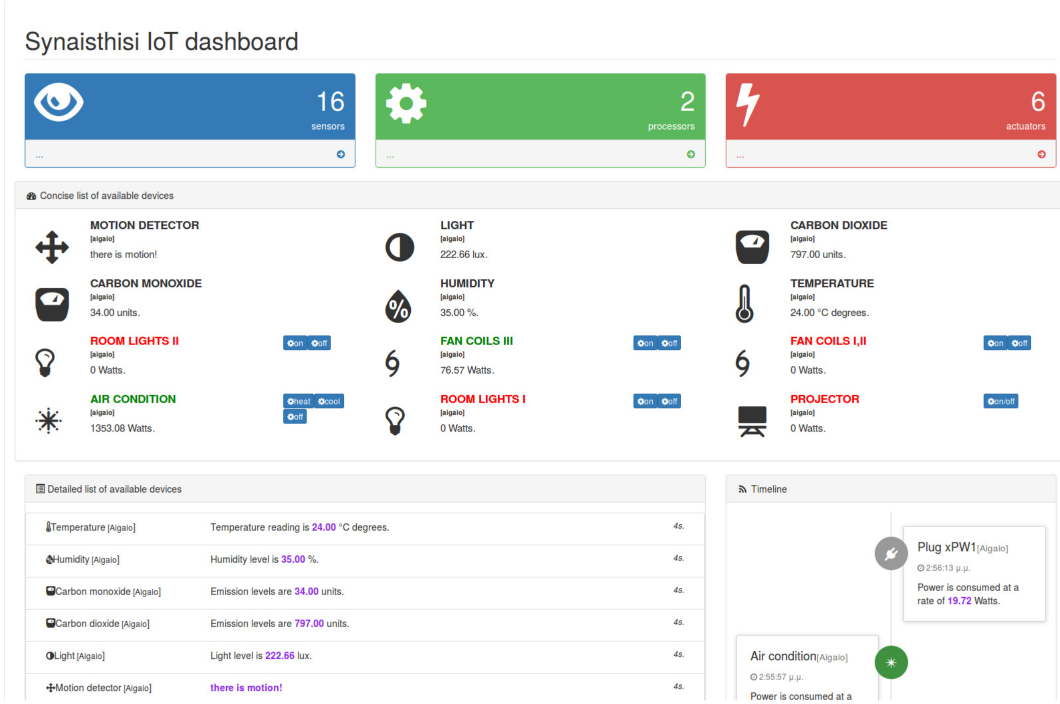

Figure 2: The smart room dashboard offers monitoring and remote control capabilities.

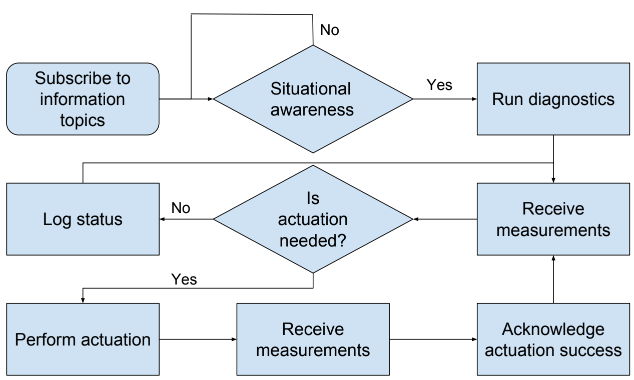

Figure 3: Flowchart of the DM's functionality.

Bootstrap, using the Websockets library to connect to the MOM.

5. EVALUATION

This section describes the evaluation of the smart room pilot that took place at the meeting room. The evaluation of the smart room was twofold; a) to evaluate the dashboard and the responsiveness of the room services and b) to evaluate the user experience upon presence within a meeting controlled by the DM. Evaluation was based upon qualitative answers by both meeting coordinators and participants.

More specifically, we prepared two separate questionnaires, targeting a) the coordinator of the meeting, i.e. the person who has booked the room and has been granted with the appropriate permissions to override the DM; and b) the visitor i.e., a person who participated in a meeting, however he/she was not interacting with the DM. Coordinators commit during the room booking to complete their questionnaire, while visitors complete theirs, voluntarily. Coordinators are asked questions, which measure both their satisfaction on the usage of the room and also collect input which will allow us to further improve the dashboard functionality. On the other hand, visitors completed their questionnaires voluntarily and their responses have been used to measure the essence of their experience, at a higher level.

5.1 Questionnaires: Question lists and user answers

At the following, we present both sets of questions, along with the possible answers and the results of the user evaluation, from 10 coordinators and 20 visitors, accordingly.

Coordinator questionnaire.

1. *Does each icon successfully actuate its associated device? (1:Unsuccessful – 5: Very successful)*; the users in general felt that each icon successfully actuated its associated device, since the average score was 4.4.

2. *Please, report any problems related with the actuation of the devices. (Free Text)*; main problems reported were: a) need to first switch on the lights and then control them (1 user), b) dashboard needed reloading (2 users) and c) sometimes delays in actuations (3 users).

3. *Are you satisfied with the responsiveness of the interface to the real world events in the room? (1: Very dissatisfied – 5: Very satisfied)*; the average score was 4.1, which indicates that responsiveness can further be improved. However we feel that the users were satisfied.

4. *Did you experience any delay between the manual triggering of a device and the status update on the dashboard? (no delay/short delay/long delay)*; all users reported short

Table 1: Scenarios, rules and actions that are used by our decision maker.

Condition	Actions
i) Fire alarm	
Temperature is high and emission levels are high	Repeated announcement "Fire alert is activated", actuate alert notification
ii) Occupancy-dependent decisions	
The room is empty	Turn all appliances off
First person enters the room	Lights turn on, announcement "Welcome, people"
Start of the meeting	Front lights off, projector on, announcement "The meeting is about to start"
End of the meeting	Turn all appliances off
The room is occupied and current time is between 00:00 and 06:00	Actuate alert notification
iii) Temperature optimization	
Temperature is higher than the target, outdoor temperature is higher than indoor	Turn A/C in cooling mode, or fan coils on
Temperature is lower than the target, outdoor temperature is lower than indoor	Turn A/C in heating mode, or fan coils on
Temperature is lower than the target, outdoor temperature is higher than indoor	Turn all off, announce "Please open the windows for air refreshment"
Temperature is higher than the target, outdoor temperature is lower than indoor	Turn all off, announce "Please open the windows for air refreshment"
Temperature is equal to target	Turn heating/cooling appliances off
The room is empty	Turn heating/cooling appliances off

delays.

5. Do you think the Dashboard controls are intuitive for a first-time user? (1: Not intuitive – 5: Very intuitive); the users felt that the dashboard was quite intuitive, since the average score was 3.9; however we feel that it still needs a few improvements.

6. Are you satisfied with the colors (scheme/sizes)? (1: Very dissatisfied – 5: Very satisfied); the average score was 4.3, thus we we can conclude that users were satisfied with the colors/sizes. We should note that all smartphone users were very satisfied.

7. If you experienced important issues with the layout, please report them. (Free Text); Important issues denoted by users were: a) too much information is displayed on the dashboard (1 user), b) icons should change color according to their status (5 users) and c) devices should be categorized to sensors and actuators (1 user).

8. What kind of device did you test the dashboard on? (Laptop/Tablet/Smartphone); 7 users used the dashboard from a laptop, while 3 from a smartphone.

9. What is your gender? (Male/Female); 9 male and 1 female users took part in this evaluation.

10. Please, specify your age. (<18/18-25/25-30/30-40/ >40); we had 0, 0, 1, 6, 3, participants of the aforementioned age groups respectively. Not all adult age groups were represented, since typically meeting coordinators are of higher age.

11. What is your educational level? (High School graduate/Bachelor's degree/Master's degree/PhD degree/Other); users of not all educational levels took part in this evaluation. We had 2 users with at least a Bachelor, 2 with a Master and 6 with a PhD. This result is in accordance to the one of the previous question.

Visitor questionnaire.

1. Were you satisfied with the room temperature? (1: Very dissatisfied – 5: Very satisfied); in general visitors were satisfied with the room temperature. The average score was 4.05, which indicated that the temperature goals set from the DM were satisfactory.

2. Were you satisfied with the room lighting? (1: Very dissatisfied – 5: Very satisfied); visitors were more satisfied with ambient light. The average score was 4.3.

3. Did you feel your privacy being violated during your stay at the room (e.g. due to cameras and microphones present?) (1: Not at all – 5: Extremely); only one visitor felt that his privacy was violated during his stay at the room due to the presence of cameras and microphones. The average score was 1.95. This score could be improved if these devices are hidden but visitors would still be informed of their existence.

4. Were you satisfied with the automations of the room? (1: Very dissatisfied – 5: Very satisfied); the average score regarding the automations of the room was 3.9 which indicates that they could be improved. Visitors did not like that heating devices and lights should first be turned on manually. However this was due to infrastructure limitations.

5. If you experienced important issues with the room, please report them. (Free Text); only a few users replied to this question. One user did not like the fact that the browser of his Android phone could not open the smart room dashboard, due to an incompatibility with websockets. Moreover, 2 other users criticized the fact that the dashboard needed refreshing sometimes. However we feel that these problems occurred due to outdated software they used.

6. If you have any suggestions, please share them with us. (Free Text); few users replied to this question. Amongst the harvested answers we should note that 2 users did not like the synthetic voice, since they felt that it was a bit "artificial". One user suggested that temperature should be updated more frequently.

7. What is your gender? (Male/ Female); 15 male and 5 female users took part in this evaluation.

8. Please, specify your age. (<18/ 18-25/ 25-30/ 30-40/ >40); the ages of users varied: we had 0, 4, 3, 7 and 8 users of the aforementioned groups, thus all adult age groups were represented.

9. What is your educational level? (High School graduate/ Bachelor's degree/ Master's degree/ PhD degree/ Other); users of all educational levels took part in this evaluation: we had 1 High School graduate, 4 visitors hold a Bachelor, 8 a Master, 6 a PhD and 1 belonging to none of the above levels.

5.2 Evaluation results and remarks

Users of various ages and education levels used the smart meeting room and their experience was recorded using questionnaires. The aforementioned results prove that users have been in general quite satisfied both with the dashboard and the several automations deployed within the smart room. The feedback we had will help us further improve the deployed services and the dashboard.

6. CONCLUSIONS AND DISCUSSION

In this work we presented the SYNAISTHISI platform and a test case concerning a smart room. We equipped the room with several sensors and connected them with appropriate processing units, whose output enabled certain actuations. Having completed a series of test sessions, we came up with some initial observations that indicate the potential of the presented approach. Specifically, the environmental measurements were monitored flawlessly and were stored in a cloud infrastructure successfully. The DM was able to provide automatic room appliance and ambience control, by incorporating the current sensor measurements and by controlling the actuators in the room, without any serious problems. In some cases, due to noise, we observed some "wrong" decisions, e.g. cooling was turned off before the room temperature reached the desired point, etc. In other cases, due to network latencies, large messages (e.g. video frames/audio) were not delivered in time. However, packet loss was limited, thus non time-critical services like file recording worked as expected. Still, these problems were rare and did not reduce the room's functionality. Moreover, we should emphasize that the proposed platform facilitated the integration of several heterogeneous sensors. As described in Section 4, multiple programming languages and several development boards were incorporated, but the use of the MoM allowed their flawless integration with the main platform.

The platform's usability has been assessed. A number of users have been asked to evaluate the platform, and fill in related questionnaires. Overall the user feedback is positive.

Future work consists of adding more S–type services to augment the perception capabilities of the room's state. We will enhance the set of P–type services by adding simple audio/video event detection, e.g. to explicitly detect the beginning/end of a presentation. A room reservation application is planned to further support the aforementioned services. We aim to integrate a set of smart agents for temperature optimization, i.e. develop a P–type service that takes into account renewable consumption levels, current electricity prices, and user preferences regarding the room temperature, and efficiently control the HVAC equipment. We also wish to implement more complex patterns that recognize events from energy, video, temperature and humidity data.

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