A Building Automation Case Study Setup and Challenges

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ABSTRACT

Smart buildings will play a fundamental role in ensuring comfort while reducing the energy required. However, due to the lack of knowledge about the operation of the smart controllers, the occupants can unintentionally increase the energy spent. Nevertheless, there is evidence that the informed and motivated user will actually cooperate with the system.

Some of the issues associated with researching control systems in the context of building automation are difficult to address, because of the chronic lack of effective laboratory settings for experimentation. In this paper, we describe a system representative of the usual complexity found in cyber-physical systems, whose purpose is to address the needs for experimenting with building automation, with a focus on control systems and gamification. Designed with pragmatic concerns, this system presents a unique set of challenges and opportunities to research a new generation of software control systems, and supporting interfaces, that leverage the occupants' behaviour.

CCS CONCEPTS

• **Networks → Cyber-physical networks**; • **Human-centered computing → Collaborative and social computing design and evaluation methods**; *Collaborative interaction*; • **Computer systems organization → ***Sensor networks*; *Sensors and actuators*;

KEYWORDS

smart room, gamification, control, human-in-the-loop.

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1 INTRODUCTION

Energy management in buildings has the potential to greatly cut CO_2 emissions [39]. Traditionally, this reduction has been mainly sought via the design of sophisticated control systems. However, these rarely account for the human behavior, beyond their presence in the building [9, 40], and (averaged) preferences of comfort [32].

Obviously, it is crucial for the occupants' satisfaction that they are able to override the system and set their preferences, which can have a great impact in the green performance of the control system [6, 10]. Moreover, the occupants are seldom informed about the operation of the control system [28, 36], which hinders the potential human/control system cooperation.

Fueled by this realization, and by cheaper metering technologies, researchers observed that the actual energy consumption was greater than predicted and that indeed the culprit was the occupant [11, 17]. This spurred research into control systems that consider the human-in-the-loop (e.g., [34, 41]).

Clearly, there is a trade-off between user comfort and energy reduction. However, there is evidence that the informed user will willingly sacrifice some comfort for increased energy reduction [5, 30]. For example, as reported in [5] and references therein, when the occupants were provided with more information about their energy consumption, they successfully adapted their behaviour to consume less. Moreover, electric appliances represent an increasing share of energy consumption [30], meaning that engaging with the occupants to reduce their use could lead to significant energy efficiency, without hindering their comfort.

Gamification [7] techniques have shown some promising results. For example, Morganti et al. [26] report on how serious games informing the occupants about power consumption led to a higher level of awareness and reduction. However, in the same paper, the authors refer to conflicting results in longer time periods, and the lack of real-world studies.

Research in gamification for energy reduction is still in its infancy, and, to the best of our knowledge, there is no work that explores the coordination of gamification strategies with advanced controllers for energy reduction when the two fields (control and gamification) have the same objective (see Dounis and Caraiscos [9], Shaikh et al. [34], Sousa Nunes et al. [35] for a survey on control). An anecdote is reported by Zeiler et al. [41], where the occupants did not turn off the appliances before the lunch break.

Our vision is to research advanced control systems, where the occupants play a proactive role in the system: not just part of the environment, but also as sensors/actuators, through the use of incentives. Moreover, we aim at bridging the communication gap between system designers and end users, using gamification to educate the user about the decisions the control system makes. To this end, recognizing that there is a need for real-world experiments [18], we report on the retrofitting of an office room with sensors, actuators, user interfaces, and an open API, to serve as a test bench

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for upcoming research. Furthermore, we highlight some of the intended applications.

2 CHALLENGES AND APPLICATIONS

The room we now introduce presents a combination of key challenges that are characteristic of Cyber-Physical Systems (CPSs):

(1) the room is located in a dated building, having windows and window blinders that are manually operated (this is where the occupants can act);
(2) it is a shared space, so individual occupant preferences and potential conflicts need to be accommodated [38, 41], even with the limited availability of actuators;
(3) the presence of occupants is difficult to predict, as some work from home occasionally;
(4) there are critical controlled systems in the room that need to be regulated, and this regulation is sensitive to the decisions made by the occupants and the room's control system; and
(5) there is a wide range of extra data about the occupants (e.g., schedules and meetings).

As potential applications, we highlight the following:

- design and validation of human-in-the-loop control systems [27, 35] with gamification;
- validation of controllers that rely on human activity predictions;
- design of usable domain specific languages [3] for the specification of controllers and configuration of Internet of Things (IoT) devices;
- application of hybrid system safety verification techniques (e.g., event processing rules verification [24], simulation stability [4, 12, 37]);
- deployment of novel simulation techniques (e.g., non-deterministic [20, 25], hybrid [15, 22], cooperative [8, 13, 14]);
- development of IoT self-diagnosing techniques [16];
- deployment of novel model-based testing techniques [2]; and
- development of obfuscation techniques that ensure the privacy of the occupants.

3 CYBER-PHYSICAL HUMAN SETUP

This setup was created as part of NOVA LINCS Smartlab project, in the Computer Science Department (FCT NOVA). It is used by MSc and PhD students as a computer science open space. Inside the room, there is a fish tank installed, managed by the Open Aquarium [23] hardware solution. The plant is summarized in fig. 1.

Following the definition in Lee [21], two CPSs can be identified: the room and the fish tank.

3.1 Physical Setup

The plant is composed by:

Humans — they produce heat and affect energy consumption;

Structural elements — Apart from a door and five windows, there are ten workstations and a meeting table in the room;

Fish Tank system — changes in the state of the room affect the fish tank control system and vice versa.

Tables 1 and 2 summarize the types of sensors available.

In table 3 we present the actuators available in the room and in table 4 we present the actuators available in the fish tank.

Table 1: Room sensors.

Component	Description
Estimote beacons	Measure temperature and luminance, and provides indoor location.
Power sockets	Measure power (Watts) and current (Amperes) flow.
Energy meters	Measure AC power consumption.
Outdoor thermometer	Measures the outdoor air temperature.
Outdoor sensor	Measures UV, infrared, and visible light.
Humans	Provide (upon request) information regarding the subjective evaluation of the environment conditions.

Table 2: Fish tank sensors.

Component	Description
Water level	Measures the water level.
Ph sensor	Measures the water's Ph.
Thermistor	Measures the temperature of the water.

Table 3: Available actuators in the room.

Component	Description
Power Sockets	Can be enabled or disabled.
Lifx Lights	Can be set on or off, and hue, saturation and brightness can be changed.
Conventional Halogen Lights	Can be set on or off.
Heaters	Can be set on or off to increase the room temperature.
AC Unit	Is controlled by setting a desired room temperature.
Humans	Can be asked to perform tasks that cannot otherwise be accomplished.

Table 4: Available actuators in the fish tank.

Component	Description
Ventilator	When activated, lowers the water temperature.
Lights	Provides high-intensity light to aid in plant growth.
Feeder	Releases food into the aquarium
Water Heater	Increases the water temperature.

3.2 Cyber Setup

To implement the server-side component we choose the WSO2 IoT server platform [31]. This solution provides device and user management, analytics, web portals, and support for adopted IoT protocols like MQTT or XMPP [19].

To support the sensors and actuators presented in tables 1 to 4, new device plugins were implemented.

After a new device type is deployed to the IoT platform, it is possible to add/remove instances of devices and edit device details using either the publicly available platform management REST API or the device management web portal. Control rules can be defined at the device plugin level using the WSO2 complex event processor, or external controllers can access and alter the device state using the published device REST API.

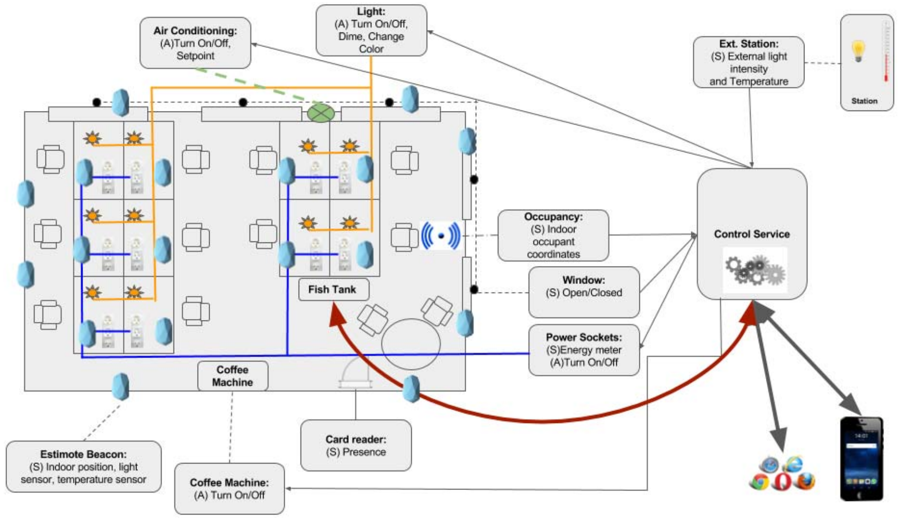

Figure 1: Smartlab room layout.

3.3 Human-in-the-Loop

Users can interact with the system using a mobile app, the WSO2 management portal, or the digital voice-enabled assistant in the room. The assistant supports natural language interactions, and simple commands can be issued to control the devices.

In the mobile application, users can set the desired room conditions, follow their progress in potential games and check the tasks that are being requested by the system. The mobile application also provides the user's location.

In the device management portal, it is possible to visualize the measurements collected from the devices, and issue commands to the supervisory controller, over the internet.

4 RELATED SETUPS

Due to the need for real-world experiments, there has been some effort to instrument existing rooms and buildings to validate novel control systems. We focus on the most recent works [29, 33, 41].

In [41], the authors have instrumented an office floor for their experiments. One of the occupant's desk was equipped with reflector heating lamps, whose purpose was to heat the occupant's hands, and an infra-red sensor, to measure the temperature of the occupant's hands. Furthermore, a wireless sensor network was installed, that could track the participants' position on the floor and, therefore, measure their use of electrical appliances.

The work in [33] describes a smart meeting room, where Microsoft Kinect cameras are used to detect, identify and track the occupants. As briefly described by [1], the meeting room is equipped with temperature sensors and HVAC, and automated lights.

Finally, in [29], a public building was equipped with power meters and device localization technology such as Bluetooth beacons and Near-Field-Communication chips. This allowed the authors to validate a novel gamification approach that aims at promoting energy efficient behaviour by the occupants.

These works complement ours. The main distinguishing factor is the purpose and configuration of the setup. We use a well-known IoT open-source framework that allows an easier integration of new control systems, as well as apps, for the purpose of combining gamification approaches with controllers.

5 CONCLUSION

We report a setup of a representative CPS, whose purpose is to foster future research in software design, in this case, connecting gamification approaches with advanced controllers, leveraging the willingness of occupants to collaborate with the system.

As future and ongoing work, we intend to explore applications such as the development of gamification techniques, deployment of novel human-machine interfaces and streamline the development process of these controllers using model-driven techniques. Furthermore, the sensory data is currently available online, but due to privacy issues, it cannot be made public. We intend to apply (real-time) obfuscation algorithms on this data, to make it public while preserving the occupant's privacy, to foster new research.

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