A Building Automation Case Study - Setup and Challenges

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ABSTRACT

Occupant behavior can wreck havoc in the performance indicators of smart building controllers, and this is usually caused by lack of knowledge about the operation of the system. However, there is evidence that the informed and motivated user will actually cooperate with the system.

In this paper, we describe a system representative of the usual complexity found in cyber-physical systems, whose purpose is to address the chronic lack of real experiments involving gamification and control systems, in the context of building automation. 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' behavior.

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 [42]. 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, 43], and (averaged) preferences of comfort [34].

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 performance of the control system [6, 10]. Moreover, the occupants are seldom properly informed about the operation of the control system [30, 38], 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 the predicted consumption, and that indeed the culprit was the occupant [11, 19]. This spurred the research into control systems that considers the human-in-the-loop (e.g., [36, 44]).

Clearly, there is a trade-of between user comfort and energy reduction. However, there is evidence that the informed user will willingly sacrifice some comfort, for increased energy reduction [5, 32]. For example, as reported in [5] and references therein, when the occupants where provided with more information about their energy consumption, they successfully adapted their behavior to consume less. Moreover, electric appliances represent an increasing share of energy consumption [32], 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 [13, 28]. For example, Morganti et al. [28] reports 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. [36], Sousa Nunes et al. [37] for a survey on control). An example of this deficit is reported in Zeiler et al. [44], where, due to the presence of a smart control system, the occupants did not bother turning off the appliances before the lunch break, leading to wasteful energy consumption.

Our vision is to research advanced control systems, where the occupants play a fundamental role in the system, not just as passive "plant" models, 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 [20], we report on the retro-fitting of an office room with sensors, actuators, user interfaces, and an open API, to serve as test bench for upcoming research. Furthermore, we highlight some of the intended applications.

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2 CHALLENGES AND APPLICATIONS

This room presents a combination of key challenges that are characteristic of Cyber-Physical Systems:

1. the room has been in use for over a decade, having uncontrollable actuators, such as windows and window blinders (this is where the occupants can act);
2. it is a shared space, so individual occupant preferences and potential conflicts need to be accommodated [41, 44], even with limited availability of actuators;
3. the presence of occupants is difficult to predict, as some work from home occasionally, making it difficult to employ occupancy predictors;
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 (e.g., schedules and meetings) about the occupants to take advantage of.

As potential applications, we highlight the following:

- design and validation of human-in-the-loop control systems [29, 37] with gamification;
- validation of domain specific human activity predictive controllers;
- usable domain specific language design [3] for the specification of controllers and configuration of IoT devices;
- hybrid system safety verification techniques (e.g., event processing rules verification [26], simulation stability [4, 14, 39]);
- deployment of novel simulation techniques (e.g., non-deterministic simulations [22, 27], hybrid system simulations [17, 24], co-simulations [8, 15, 16]);
- development of IoT self-diagnosing techniques [18];
- 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 NovaLincs's Smartlab project, in the Computer Science department of the Faculty of Sciences and Technology (FCT NOVA). The place 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 [25] hardware solution. The plant is summarized in fig. 1.

Following the definition in Lee [23], two CPSs can be identified: the room and the fish tank.

3.1 Physical

The plant is composed by:

Humans — they produce heat and trigger actions that affect energy consumption.

Structural elements — Apart from doors, 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's control system, and vice versa.

Tables 1 and 2 summarize the types of sensors that are 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/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

To implement the server-side component, we choose the WSO2 IOT Server platform [33, 40]. One of the goals of this platform is to implement a scalable server-side IoT Platform [12]. This solution provides capabilities like device and user management, analytics, web portals, support for adopted IoT protocols like MQTT, XMPP and HTTP [21].

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 APIs 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 APIs.

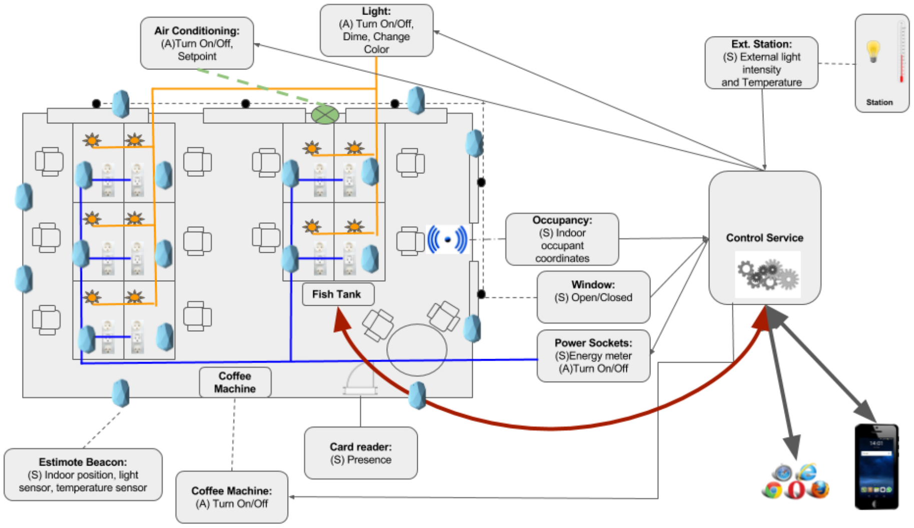

Figure 1: Smartlab room layout.

3.3 Human-in-the-Loop

Users interact with the system using a mobile application, the WSO2 device management portal, or the digital voice enabled assistant available in the laboratory. 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 serves the function of providing the user 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 into instrumenting existing rooms and buildings to validate novel control systems. We focus on the most recent works [31, 35, 44].

In [44], 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 participants position in the floor, and therefore measure their use of electrical appliances.

The work in [35] describes a smart meeting room, where Microsoft Kinect cameras are used to detect, identify and track the occupants. As briefly described in [1], the meeting room is equipped with temperature sensors and HVAC, and automated lights.

Finally, in [31], 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 behavior by the occupants.

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

5 CONCLUSION

We report an experimental setup for a representative cyber physical system, whose purpose is to foster future research in software design, in this case, connecting gamification approaches with sophisticated controller, 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, currently the sensory data is 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 occupants privacy.

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