An Architecture for Green Smart Homes Controlled by End Users

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ABSTRACT

Automations can help support the achievement of various types of goals in a smart home. We present an architecture enabling the possibility of supporting user goals consistent with the principles of a circular economy (such as energy saving and waste recycling). It includes meta-design tools for creating automations that better fit user needs and controlling their execution through innovative modalities based on conversational agents and augmented reality, and a home Digital Twin useful for supporting relevant simulations and analytics to understand the potential impact of specific automations on aspects relevant for circular economy.

CCS CONCEPTS

• Human-centered computing → Ambient intelligence

KEYWORDS

End-User Development, Green Smart Home, Digital Twin

1 Introduction

The number of connected sensors and objects is increasing exponentially. These devices offer significant enhancements to our quality of life. From increasing comfort and sustainability in our homes through automations and efficient energy management to providing essential assistance to the elderly and enabling comprehensive remote monitoring of various systems, the impact of the Internet of Things (IoT) is profound and far-reaching. Smart homes leverage this wide variety of connected devices, smart appliances, and external services to perform actions and automated routines, to reduce the effort of daily actions but also optimise resource use and save money. Yet, the potential of this technological abundance risks falling short if users are not adequately empowered to control and adapt the ecosystem of connected objects, devices, and services to their individual needs. A relevant EUD (End-User Development) [9] approach is trigger-action programming (TAP), which can be a connection point between the IoT technologies and the users. TAP does not require specific algorithmic skills or knowledge of complex programming structures [4, 5, 6], and previous work [16] showed that average users can successfully engage in TAP with multiple triggers and actions. In a smart environment, usually there are multiple active automations, whose resulting behaviours can interfere among them, and generate undesired effects. To manage multiple automations, we have identified different cases to address [2, 10]. Another important aspect is the possibility to show and log what happens with such automations. These visualisations can provide insights into how the environment behaves and users' needs [3, 11], and they emerge as particularly relevant for energy-saving objectives [13]. A step up from monitoring an environment through an interactive dashboard is the introduction of a Digital Twin (DT) [15, 17, 18] of the considered environment. DTs are physical and/or virtual machines or computer-based models that simulate, emulate, mirror, or 'twin' the life of a physical entity, which may be an object, a process, a human, or a human-related feature [1].

2 Requirements

The architecture of the proposed system should provide an approach to the sustainable management of a smart home. Thus, the defined requirements for the solution are:

- **Provide users with descriptions of the state of the smart space** to ensure that users form a correct mental model of the environment.
- **End-user creation and modification of automations** through intuitive, innovative and no-code interfaces, that exploit augmented reality [14] or natural language interactions.
- **Management of dependencies among multiple automations** guiding users to the detection, understanding, and resolution of issues between automations, and between the deployed automations and the sustainability long-term objectives.
- **Introduction of prediction and simulation capabilities based on** the smart home historical data, applying Machine Learning (ML) and Deep Learning (DL) techniques to these data to offer energy consumption predictions.
- **Provide automation explanations** concerning the possible execution and effects of the automations, answering questions such as "why" or "why not" an automation can be performed in a given context, or "what-if" some automation parameters change, or

"how to be that" or "how to still be this" to understand what changes can be performed to maintain or achieve a certain effect.

- **Integration of a Digital Twin for enhanced management, visualisation, and analytics** providing a real-time, dynamic representation of the physical space, that users can use to visualise and get insights on their home's energy consumption, resource utilisation, and automation impacts.

3 Architecture

The functionalities of the DT are grouped into various modules that are herewith described (see Figure 1).

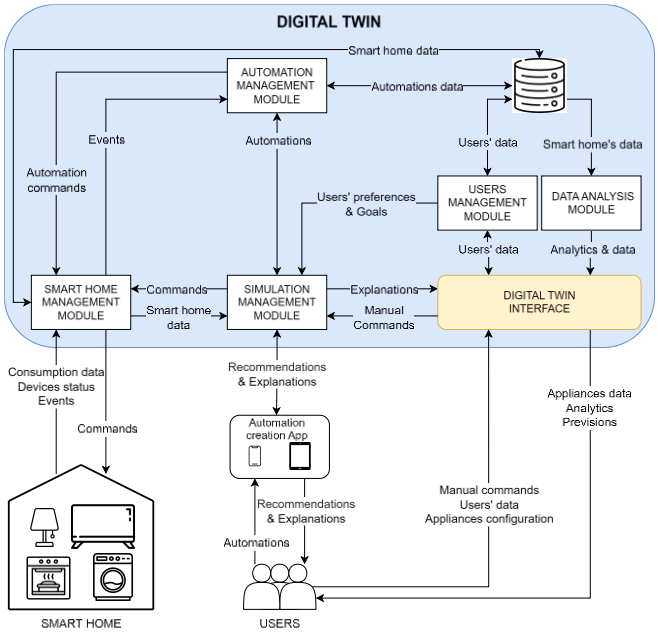

Figure 1: Architecture of the proposed system.

The *Smart Home Management Module* coordinates the communication between the DT and smart home appliances. It periodically gathers energy consumption data from the appliances and manages the execution of automations and the activation of instant actions (e.g., vocal commands such as turning on a light). For this purpose, we will also exploit the functionalities provided by Home Assistant.

The *Automation Management Module* handles automation operations within the system. It manages the saving and deleting of automations in the database based on information received from the Simulation Management Module. Additionally, it is responsible for executing automations when their activation conditions are met and, in case, sending their commands to relevant appliances.

The *User Management Module* oversees user profiles and preferences, allowing users to save and edit their information inside the system. Users can also specify their preferences on topics like energy conservation, environmental impact, and other long-term goals they want to pursue.

The *Data Analysis Module* furnishes the DT with diverse analytics and graphs derived from the gathered data. This module provides insights based on the smart home history, such as showing the house's energy consumption in the last hour, day, or month, and on instant data, e.g., the current temperature of a specified room or the current appliances usage. This module also provides information on the list of automations saved into the database and their activation status. Furthermore, the module offers energy consumption predictions utilising ML and DL techniques.

Through the *Digital Twin Interface* users can interact with the previous modules and access the features offered by the DT.

The *Simulation Management Module* intervenes before saving an automation created by a user or before a manual command to a specific home appliance is committed, to check if these operations interfere with the ones already present in the system. In case of interference, the module guides the user in solving the problem. This module encompasses two components: the *Conflict management component*, and the *Explanation component*. The former is tasked to identify and solve possible issues (such as conflicts) that may emerge between the automation the user wants to create (or the command to execute) and the automations saved in the database. Additionally, this component evaluates the feasibility of the actions included in the automations or manual commands with the maximum consumption threshold, preventing any scenarios in which the power consumption exceeds such a threshold. The *Explanation* component provides users with explanations about the previous component's outcome and recommendations on how to improve the home automations. Such recommendations are made considering the profile of the users creating the automation, particularly their long-term goals and the possible economic savings obtained from rescheduling the automation at hand.

In conclusion, we have presented the logical architecture for a green smart home. In the following, a prototype implementation of this architecture integrated with ChatGPT to make the conversation more fluent will be implemented and deployed for its use in real contexts.

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