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Design of Incentive & Intelligent User Interfaces (I^2UI) for behavior change : energy management for smart homes as case study

Interfaces utilisateur incitatives et intelligentes (I^2UI) pour le changement de comportement : cas de la gestion de l'énergie pour les maisons intelligentes

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ABSTRACT

Targeting home energy management, we investigate Incentive & Intelligent UIs (I^2UI) designed to help users (1) voluntarily change their behavior to reduce and (2) optimise energy use. Thanks to this combination, we envision human-system cooperation through Co-learning and Co-decision as an approach to better engage and support users throughout the behaviour change process.

CCS CONCEPTS

• **Human-centered computing** → **HCI theory, concepts and models.**

KEYWORDS

Incentive & Intelligent User Interface, Persuasion, Human AI Interaction, Energy Management.

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RÉSUMÉ

Avec la gestion de l'énergie comme domaine d'application, cette thèse étudie les interfaces incitatives & intelligentes (I²UI) conçues pour aider des occupants à (1) réduire et (2) optimiser l'usage de l'énergie. Par cette approche conjointe, nous visons une coopération humain-système par du co-apprentissage et de la co-décision pour mieux engager et accompagner les utilisateurs dans le changement de comportement.

MOTS CLÉS

Interface Incitative & Intelligente, Persuasion, Interaction Homme-IA, Système de Gestion de l'Énergie.

INTRODUCTION

Incentive User Interfaces (UIs) are designed to assist users in a voluntary behaviour change process [6, 13, 14, 27]. On this research, the reduction of energy consumption is one of the most studied application domains [9, 24]. Intelligent UIs are designed to assist humans in diverse use scenarios[17, 32], including how to save energy at home[7, 22]. However, each approach faces challenges and limitations that hinder its energy-saving potential. User's lack of knowledge and capacity can limit the effectiveness of Incentive UIs, particularly in the long term[2, 13, 23, 37]. As for Intelligent UIs, a lack of intelligibility undermines the human-system cooperation[35, 36].

Targeting home energy management systems, our research question is: How can Incentive UIs be designed leveraging the power of Intelligent UIs regarding energy use behaviors. Thanks to this combination, we envision human-system cooperation through Co-learning and Co-decision as an approach to better engage and support users throughout the behaviour change process. In the following sections, we detail the context of our research and its motivation, as well as our research approach, research methodology and expected contributions.

RESEARCH CONTEXT AND MOTIVATION

Household energy consumption stands for 28% of energy consumption in the EU, 2020[5]. Despite improved appliance efficiency over the past decades, consumption behavior remains a major factor on energy use[11, 12, 12, 16, 19, 38]. To achieve emissions reductions and climate goals[4], energy sobriety in everyday activity is crucial.

Incentive UIs can help to raise awareness of energy consumption and assist users to adopt more energy-sober behaviours[9, 10, 13]. However, fully understanding the energy impact of one's activity can be a daunting task for average consumers[1, 2, 21, 28, 36, 37]. Users' limited capacity may in turn limit the effectiveness of Incentive UIs as knowledge and skills are a key part in many behaviour change models[27], of which many Incentive UIs are built upon. In addition, current Incentive UI designs overlook habitual behavior and may lack long-term efficacy[13, 27].

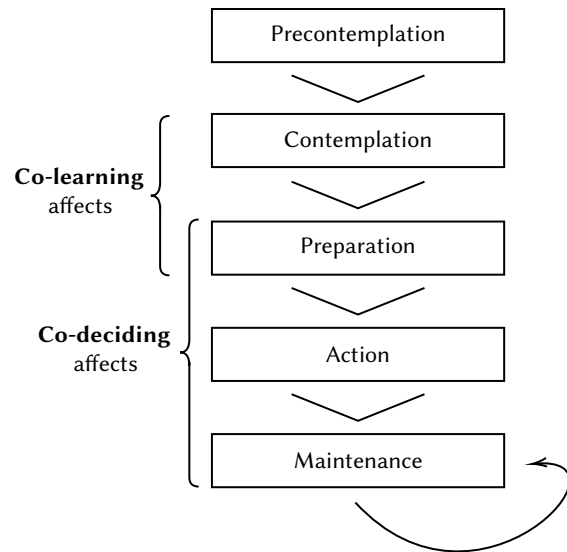


Figure 1: Co-learning and Co-deciding in TransTheoretical Model(TTM)

Intelligent UIs present new opportunities and challenges for home energy management systems. With learning algorithms, energy-saving possibilities become accessible to a broader audience, reducing user effort, knowledge and skill requirements. However, as intelligent systems exhibit substantial differences from conventional systems, HCI researchers face a new set of challenges when it comes to interaction designs for or powered by learning algorithms[17].

Existing home energy management systems using intelligent systems struggle to consider complex contextual information, leading to user dissatisfaction[36, 37]. Such an issues are often neglected in UI and system design, making it difficult for users to improve their experience[36]. A lack of intelligibility can exacerbate user frustration and hinder system’s credibility[35, 36].

The issues mentioned in current research suggest a combined approach for sustainable behavior change and reducing energy consumption. However, few studies exist on this approach, hence our motivation. We envision a smart home energy management system using *I²UI* to engage and support behavior change through human-system cooperation.

RESEARCH APPROACH

We aim to combine Incentive UI and Intelligent UI into a digital partner while users remain in control over their home, encouraging human-system cooperation towards the common goal of optimizing and reducing energy consumption at home. Human-system cooperation should leverage user engagement and support of a sustainable change towards energy sobriety.

Particularly, our originality, we study two aspects of human-system cooperation: **Co-learning** and **Co-deciding**, related to behaviour change techniques(BCT) [23] found adequate for the context of home energy management [30] to improve knowledge and skills (i.e., MoA: Mechanisms of Action[23]) about energy consumption, thus to facilitate behaviour change.

In **Co-learning**, the user and the system construct a common model of energy consumption at home through interactive annotation, which involves the self-monitor BCT. Users are not always aware of their behaviours as they are not always rational and intentional[8, 12, 16, 19, 25, 26, 29, 31, 38]. energy is intangible thus is hard to keep track of one’s consumption[10]. Interactive annotation on energy consumption data is shown to provoke deep self-reflection[15]. Co-learning leverages the power of sensors and intelligent systems to record and organise events that may have been overlooked by the user. Through interactive annotation, users can be reminded of these events and provide additional key data such as motivations and intentions that are unobtainable through sensors. In Co-learning, such a BCT can be better supported, thus increase user’s awareness and understanding of the cause-effect relation in everyday activity, evoking MoAs regarding knowledge, beliefs and attention to facilitate the behaviour change process[3, 27]. Additionally, Co-learning addresses the challenge of data collection as users can provide valuable contextual data in interactive annotation.

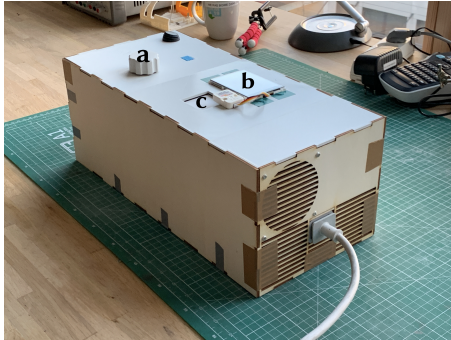


Figure 2: The “Feel heal? Feel-it” prototype thermostat. On the prototype: (a) a rotating knob/button, (b) a screen, (c) a variable temperature Peltier module. Before use, users are guided to complete a calibration process to fine tune the thermal stimulus. The prototype adjust it’s thermal stimulus based on a user’s average fingertip temperature, the room temperature as well as the user’s current thermal sensation. After each adjustment, the prototype provides a thermal stimulus reflecting the estimated level of comfort associated with the new setpoint through the Peltier module, allowing users to feel the thermal stimulus through touch and decide if further adjustment is necessary.

In **Co-deciding**, the system and the user cooperatively decide on action plans to save energy based on the common model constructed in Co-learning. Users keep control of the final decision over what action to perform. Research works have previously demonstrated that smart systems can compensate for user’s lack of capacity and knowledge to act on their intention of behaviour change[1, 18, 28, 36]. But this approach can suffer from the lack of long term effectiveness if users blindly adopt system’s suggestions without understanding them[27, 36, 37]. As Co-learning helps the user and the system builds a common model of energy use, it serves as a scaffolding to better support BCTs involved in Co-deciding. Techniques such as goal setting and action planning may become more effective as the knowledge accumulated in Co-learning can help the user better understand the system’s propositions.

RESEARCH PLAN AND EXPECTED CONTRIBUTIONS

This doctoral research is planned in the following way.

Step 1: Case study: the use and the design of thermostat UI. The case study provides us an opportunity to gain insight on simultaneously one of the most energy consuming end-uses in homes[5] while also being heavily influence by inhabitants’ habits, preferences and believes[25, 29, 33]: space heating. We explore design alternatives to (a.) improve the learnability of the cause-consequence relationship between setting a setpoint and the eventual thermal sensation, and (b.) facilitate the process of choosing a setpoint that is coherent with the actual thermal comfort need.

Step 2: Generalisation of findings in step 1 to other everyday activities in the task of integrative annotation in order to achieve optimal Co-learning.

Step 3: The study of optimal Co-deciding to effectively and sustainably incited users towards a more efficient energy consumption behaviour at home following Co-learning.

For each step, we adopt the same research methodology: under one or several identified theoretical frameworks(e.g. [27, 30, 33, 34]), we develop and evaluate novel interaction designs regarding it’s effectiveness in Co-learning, Co-deciding, or both at the same time. The expected contributions of our research include new interaction techniques for I^2UI and conceptual contributions of I^2UI design framework(i.e. Co-learning and Co-deciding).

CURRENT STATE OF WORK & PROSPECTIVE

We are currently at the step 1 of our research plan. We proposed new interaction design principles called “Feelback” and “Feelforward” that rely on sensory modalities to reflect and guide a user’s action as our fist conceptual contribution, enriching Norman’s feedback and feedforward design principles.

Current thermostat design lacks the immediate feedback[20, 25, 33] in the appropriate modality to allow users to associate an particular setting with a certain level of comfort, resulting a low learnability of the action-consequence relation in regards to comfort. “Feelback” and “Feelforward” are informed by the behaviour model proposed in [33] and the “interaction frogger” design framework[34]. The

interaction frogger framework[34] suggests that, to improve the learnability, a interaction design with a stronger coupling between action and function is required, namely regarding the aspects of time and modality. Therefore, in the case of thermostat, we developed the "Feel heat? feel-it!", a proof-of-concept prototype thermostat (Figure 2) which provides a immediate thermal stimulus through touch after each adjustment. The prototype illustrates the new interaction techniques which can be developed using these new principles. A between subject design is used to evaluate the new interaction technique in comparison with conventional thermostat interaction design. We hypothesise the new interaction technique can help users to better anticipate the result of each setpoint change, therefor making the adjustment more accurate and more efficient. Initial test results show that our new thermostat design allows users to more easily reflect on their usual habit of heating in regard to their actual thermal comfort needs and may prevent over-adjustments of the setpoint. Future research is needed to determine the long-term efficacy of our new thermostat interaction design. We also plan to generalise "feelback" and "feelforward" to other daily activities to increase learnability and aid users in the interactive annotation, particularly for activities where consumption occurs posteriorly(e.g. using a washing machine or a dishwasher) as the next step of our research work in regards to Co-learning. Additionally, "feelforward" will be further investigated in the context of co-deciding.

CONCLUSION

In this research work we aim to combine Intelligent UI with Incentive UI to create *I*²UI with the goal of supporting users through out the behaviour change process towards energy sober consumption behaviour thus cooperatively reducing the energy consumption at home. Our research addresses the knowledge gap regarding the use of *I*²UI to support behaviour change. Based on the hypothesized links between BCTs and MoAs, we propose designs to support the human-system cooperation in the form of "Co-learning" and "Co-deciding": two scaffolds to put a set of BTCs in-place in order to act on a particular set of MoAs [3].

We proposed the "feelback" and "feelforward" design principles to improve the learnability of the cause-consequence relation between setpoint and comfort in thermostat design, and plan to apply them in other activities in the interactive annotation task for Co-learning. Our research has implications beyond smart home energy management, as it provides a new perspective for Digital Behaviour Change Intervention (DBCI) which has many health-related applications such as food consumption, physical activity, and well-being.

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