Home Control via Mobile Devices: State of the Art and HCI Challenges under the Perspective of Diversity

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Abstract. With technological advancements in recent decades, home environments incorporate several electronic appliances in order to facilitate activities and improve users' quality of life. The increasing complexity of household appliances makes their management a nontrivial task. Mobile devices emerge as excellent platforms to enable control over such a range of appliances, providing convenience, flexibility and several interaction possibilities. However, home control via mobile devices also present some challenges, among others regarding the diversity of users. This paper presents the state of the art in home control via mobile devices. Based on an analysis of these solutions, we identify and discuss Human-Computer Interaction (HCI) challenges under the perspective of diversity. In addition, we propose a set of guidelines in order to minimize or overcome these challenges. This work may support design process of new solutions and future research focusing on domestic environment.

Keywords: diversity, domotics, smart home, home automation, mobile application.

1 Introduction

Home is a physical space which comprises social and human aspects, referring to propriety or state of mind, and reflects the lifestyles of the inhabitants [1,2]. The interplay of individual and cultural values make home a complex space. With technological advancements in recent decades, a home environment may incorporate several electronic appliances in order to facilitate activities and improve users' quality of life. These household electrical appliances increased in complexity and functionality, and present different interfaces and controls. With increasing complexity of appliances, it can be expected that interaction becomes more complex as well. With increasingly complex systems, it is necessary to make these functionalities available to all users, in an easier and more effective way.

Mobile devices – e.g. mobile phones, tablets and smartphones – emerge as possible platforms to enable control over such a range of appliances. They have already been adopted by users from different economic and social backgrounds, are equipped with

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several features, provide integration through a single interface are convenient to carry, and make home control possible even when not at home (e.g. in the case of the smartphone). This scenario fits the needs of users in modern societies and enables several interaction possibilities.

Much work focused on the development of solutions in this domain, especially on technical issues (cf. Section 2). However, it is important to consider Human-Computer Interaction (HCI) aspects in development of new solutions. According to Saizmaa and Kim [3], HCI studies have focused mostly on the interaction between humans and technology, not considering the importance of home aspects. Nonetheless, it is essential to consider the relation between users, technology and the domestic environment. There are some challenges of home control via mobile devices related to the diversity of users. Interface and interaction design for this context must consider these differences.

This paper presents the state of the art in home control via mobile devices. Based on analysis of these solutions, we identify and discuss HCI challenges under the perspective of diversity. In addition, we propose a set of guidelines in order to minimize or overcome these challenges. We argue that this work might support design process of new solutions and future research focusing on domestic space.

The paper is organized as follows: Section 2 presents the literature solutions composing the state of the art; Section 3 introduces HCI challenges for this context under the perspective of diversity; Section 5 discusses research issues and additionally presents the proposed guidelines; Section 6 concludes.

2 State of the Art

This section presents the state of the art of mobile devices for controlling elements of domestic environment, in the contexts of smart homes as well as home automation. The literature solutions are organized according to the kind of interface/interaction they present via mobile devices.

2.1 Textual Command Interface

Some solutions do not provide graphical interfaces to support user's interaction. They enable users to control their home through text commands, which are interpreted by home systems. These solutions use mobile telephony services to enable communication, and commands are sent via SMS (Short Messaging Service), using mobile phone.

Alheraish et al. [4], El-Medany and El-Sabry [5], Ahmad et al. [6], Khandare and Mahajan [7], Zhai and Cheng [8], Li et al. [9] and Felix and Raglend [10] propose monitoring and control systems which enable users to control household appliances, sending a message to switch appliances on or off, and check statuses. These solutions are implemented in circuit and use several sensors (e.g. fire, motion and temperature). These works focus on illumination control or home security, for example, intrusion detection, door locking or monitoring. Solutions [7,8] also use cameras. An example of a control command [7] is “STARTDEVICE 1; STOPDEVICE 4”, to turn an appliance on and turn another appliance off. Al-Ali et al. [11] focus on energy management, providing functions to users and utility companies. Users may send commands such as “Turn ON AC, Turn OFF WM” to turn air-conditioning on and washing machine off.

2.2 Textual Interface with Visual Layout

Although different interfaces may be designed for appliance control through mobile devices, several works still provide simple graphical interfaces, with textual information through forms and menus. Each appliance is represented by a name, which may be the appliance’s category or an identifier, such as “device 1”. Users change an appliance’s status using elements such as text fields, check boxes and radio buttons. It provides an enhanced interaction in comparison to textual command interfaces mentioned in the previous Section 2.1.

Some works [12,13,14,15] demonstrate this improvement and provide a dual-approach, i.e. communication occurs via SMS or an application. Both forms may be used, but the application acts as an abstraction layer for interaction since users interact with visual interface elements instead of typing commands. These applications were implemented in Java (J2ME). In the same way as interfaces, home management evolves and some systems provide other functions in addition to on/off switches, such as ventilation level [13] and lighting intensity control [14]. In [16], users may check power consumption of plugged appliances and control home via PDA applications with Bluetooth or via mobile phones with SMS. Other solutions only provide application interfaces. The solution proposed in [17] also enables users to change an appliances voltage level. HouseAway [18] provides a HTML page, the solutions in [19,20,21] provide applications with textual menus, implemented in mobile C and GVM platform, Java and Python for Symbian platforms. Systems in this section use microcontrollers, except [15], which uses an X10 controller with power line communication. Moreover, all works focus on development of a system architecture, not on HCI aspects.

2.3 Graphical Interface

With the improvement of processing power and the growth of available resources in mobile devices, several works introduced graphical elements to promote user interaction. These interface designs use colors, icons, charts, images and videos in order to provide a better user experience. Some solutions focus on development of applications and others on complete systems, but they show a particular concern regarding user interface, unlike works of the previous sections.

Yeoh et al. [22] present the e2Home system, which enables switching home appliances on or off and controlling a mobile robot. Users interact with a PDA application or sending textual commands via e-mail. It follows the dual-approach, in which application is an abstraction layer. Its interface shows icons for each appliance along with its name and a select list with its status, and a 2D home map for robot control.

Oh and Kim [23] present a similar work, which proposes to control a mobile robot through an Android smartphone for home monitoring. The application interface only displays the captured images at the center of smartphone screen and direction buttons.

In [24], a local security system is proposed for Android devices. Users can lock, unlock and check a door status from a short distance. The application displays the door status and four buttons, the system uses Arduino and Bluetooth. Solutions [25,26] provide control over appliances, image capture and alerts for security breach. HASec [25] provides an iOS application with visual elements following the iPhone Human Interface Guidelines. SmartEye [26] has a Java application which shows a home plan in 2D view, with appliances in their respective home space and color scheme to help users identifying appliances status. Rahman and Saddik [27] present a mobile client to control real home objects through 3D avatar interaction, using Second Life virtual interface. Since mobile devices lack processing power to render such 3D graphics, it uses a virtual display technique based on remote rendering graphics at a desktop computer. The implemented prototype supports touch events, such as swipe and tap, and provides illumination control, using X10 controllers.

Other systems present functionalities that are more complex. Home-in-Palm [28] provides an Android smartphone application to configure automatic changes based on time or a user's location. In [29], users may define rules, schedule tasks and set priorities, interacting with an iPhone application, an iPad client and a web client. Homer [30] provides two different applications, for iPad and iPhone, and enables users to define rules using a language based on triggers, conditions and actions, with clauses like "when", "do" and "if". The system uses a framework based on OSGi, HTTP and JSON. Dickey et al. [31] provide a cloud service-based system with an iPad application, which uses touchscreen interaction. Its interface uses several visual elements, such as touch buttons similar to on/off switches, and regulators to control light intensity with simple finger dragging. System also displays charts and uses Arduino with X10 and ZigBee communication. Solutions [32,33] generate user interfaces automatically. uniKNX [32], an iPhone application, uses configuration files, provided in system deployment, to aid systems integration with mobile device. Based on these files, it generates interface elements at runtime and provides local control. The mobile phone application presented in [33], has been implemented in ASP .NET and JavaScript, and enables users to for example open/close doors, turn lights on or off, and change color and intensity.

2.4 Multi-modal Interface and Direct Manipulation

Current mobile devices are equipped with specialized technologies and features. Accelerometers, camera, and NFC (Near Field Communication) are common examples. There are different forms of interaction beyond textual or graphical user interface, and some solutions already explore these technologies in interface and interaction design. The following solutions focus on home appliances control addressing some possibilities.

Suo et al. [34] present HouseGenie, a solution for touchscreen smartphones. It provides multi-modal interaction, integrating recognition engines of speech and handwriting, and enables to "fusion" multiple modes of interaction, e.g. when selecting an object with a click or touch and performing and action on this object by voice. It supports click, hold and drag-and-drop gestures, its interface uses several visual elements and displays a 2D home map. It uses an OSGi-based infrastructure to interconnect home appliances. Costa et al. [35] focus on interface design and also provide multi-modal interaction on their accessible interface design proposal to home control. This work provides voice and touchscreen interaction, and the design is based on icons and quadrants, targeting people with visual, hearing, motor and cognitive disabilities. The proposal was implemented over a tablet with Bluetooth communication. Kühnel et al. [36] propose using three-dimensional gestures with a smartphone for home control. The prototype was implemented for the iPhone, using accelerometer data for gesture recognition, and combining touchscreen GUI interaction for more complex actions.

Chueh and Fanjiang [37] propose a context-aware application with automatic interface generation and direct manipulation. Appliances are discovered using NFC of a smartphone, and their descriptions are downloaded through Bluetooth. The application then generates the interface based on user context. It enables local control and uses Arduino. The prototype provides TV control. Solution [38] proposes combining computer vision and ubiquitous computing. In this approach, users point a smartphone camera towards a target appliance in order to recognize it, and then select a function. It requires every appliance to have a visual fingerprint, which can be a photo or visual descriptions. Chen et al. [39] propose a touch-driven interaction system to control household appliances. Users touch target devices with a smartphone, which then captures appliance data and combines it with context information. That way, touch actions are translated into control actions. As a demonstration, three applications were implemented, to control a stereo system, media activities on TV, and to connect a smartphone to a Wi-Fi network.

Based on an analysis of these works, we identified some HCI challenges under the perspective of diversity, which we present in the next section.

3 HCI Challenges under the Perspective of Diversity

When referring to diversity, we consider users with different characteristics, including culture, age, education, gender, technical skills, knowledge, cognitive skills or use conditions. The domestic environment, due to its heterogeneous nature, always aggregates a heterogeneous set of users and diverse use situations. According to Huang [40], a key HCI challenge in mobile application design is how to make such devices usable and affordable to a heterogeneous set of users. To overcome this issue, it is necessary to consider social and contextual factors [41] in order to comprehend users' needs in their context of use, i.e. home control. The literature presented in the previous section outlines the state of the art in home control via mobile devices. Based on an analysis of these works, we identify and discuss HCI challenges under the perspective of diversity for this specific domain, which are presented below.

Home View: In order to control their homes, users must manage functions provided by household appliances, which are located in the domestic space. However, how to (re)present this space to all dwellers? Many solutions represent home as an appliances list, with no reference to the corresponding home space the appliances belong to [12,13,14,17,20,21,22,25,31]. Other solutions separate them according to location, based on room selection, such as [33]. Other approaches are to represent home as an architectural plan in a 2D-view with appliances in their respective real positions, such as in [26], or as 3D environment with virtual objects, as proposed in [27]. The 3D approach might enhance immersion and aid in elements assimilation. However, some people might have difficulties to navigate in these virtual environments. According to [34], devices identification and monitoring is faster and clearer in 2D-panoramic view than in 3D-view. Even so, 2D map representation might impose difficulties to interpretation, and changes in appliances arrangement might require map restructuring. Moreover, there is also the barrier of displaying spatial representations, 2D or 3D, in restricted screen-size devices, such as the smartphone. On the other hand, appliances lists may aid users to find the target appliance with symbolic recognition, with no spatial processing. However, it may not be as immersive as spatial representations. How to (re)present this space in order to assist diverse users with different characteristics to identify appliances through mobile devices constitutes a relevant challenge in this context.

Control Complexity: Solutions for home control involve management of a wide range of appliances, with different functions. Appliances with increasing functions make their control a very complex task. Their control via mobile devices is even more difficult, given the intrinsic characteristics of these platforms. Higher complexity functions, such as rule definition like in [29,30], bring even more challenges. According Manternaghan apud Manternaghan and Turner [30], users would like to control their home in a way that does not resemble programming. But policy definition usually uses conditional statements and commands, which requires a programming-like interaction. Nylander et al. apud Suo et al. [34] claim that users prefer using a smartphone instead of a computer to control appliances, since it is more convenient. Since smartphones have screens with limited size, a challenge for interaction design is to enable this wider range of appliance management through these devices. Providing solutions which enables users with different characteristics and usage situations to manage their home amidst this complexity constitutes another challenge.

Interface and Interaction Flexibility: Regarding interface flexibility, the configuration of appliances in a home might change over time, e.g. new appliances might be added, removed or changed in position. The application interface must reflect these changes, including the customization of automatically assigned identifiers may require customization. Some applications [13,16,32] reference household appliances and rooms as identifiers. These identifiers might be application or manufacturer defaults, might not represent the respective object/place efficiently or logically from a user's point of view. However, in many cases, graphical interface and system are tightly coupled, which makes modifications more difficult. Regarding interaction flexibility, many solutions provide only one form to interact with system. Among 36 solutions presented in the state of the art, only 3 provide multi-modal interaction [34,35,36]. Although some solutions [37,38,39] explore other forms of interaction, they do not enable users to use other interaction modes. This excludes people who cannot use a particular interaction form [42], for example, in the case of a disability or a temporal limitation due to a specific context of use. For example, a person doing a household chore, such as washing the dishes, might temporarily not be able to interact with a touchscreen interface. This challenge has not been addressed/solved in most of the work presented in the previous section.

Individuality and Multi-person Interaction: People share space and appliances with other residents at domestic environment. Several people can control several appliances, simultaneously or at different times. These appliances usually provide a single interface, common for all users. Despite home being a shared environment, each individual has a personal relationship with the space. Even if interface modification is enabled, if it remains common to all users, issues regarding individuality and diversity still persist. For example, users may accomplish routine tasks in specific way according preference (e.g. configure light intensity at a specific value). This characteristic is individual and user interface must reflect it. Another example is regarding names of home spaces. Even if application provide modifying names, for example, from “Room 1” to “John’s Room”, each user should define a particular name, such as “My Room”, which reflects the own vision of home space. It is therefore necessary to provide solutions to equitably attend all users, but also reflect the users’ individuality in each interaction, and it imposes a challenge to this context.

Privacy: Since home is a space that entails individual and personal values, we must consider privacy in solution design for domestic spaces. Solutions for home control involve appliances and environment monitoring, which bring to light the challenge of preserving people’s privacy. Several works presented in the previous section provide home security systems [4,5,6,7,8,25,26]. In order to detect intrusion, these systems monitor the environment extracting private data from cameras or sensors. The camera usage to capture image and videos in several works [7,8,14,23,25,26] aims to provide better visualization, greater reliability and feedback, but it may impact user privacy. The privacy issue must also be considered in solutions that use context information or sensor data captured from mobile device, as in [39]. Data from user profiles, such as used in [28], also highlights privacy issues, since it contains user preferences and several personal information regarding domestic routine. Home is a sacred environment in diverse cultures and the privacy concept might vary among individuals as well as among cultures. Thus information regarding domestic space requires great attention and imposes a challenge for new solutions design under this context.

Internationalization and Localization: With globalization, potential users of software are not restricted to a country or region. Home environment is a concept presented in different cultures across the world, it is thus important that home control applications may be used by users from different nations and cultural backgrounds. However, these applications are often developed to support a single language, imposing a challenge for diversity. None of the solutions presented in the previous section mention multi-language support.

3.1 Guidelines

Considering the challenges presented in the previous section, we propose a set of guidelines in order to minimize or overcome them. In this paper we consider the concept of guideline as addressed by Stephanidis et al. [43,44], as a general statement that applies in a particular context, typically subject to further interpretation so as to reflect the requirements of a particular organization or design case. Below we present our guidelines for the context of home control via mobile devices.

Consider the Dwellers' Perspective: Interface and interaction design of solutions must consider each dweller's perspective to (re)present this space, such as space division, references, rooms and names.

When adopting a spatial representation, offer an alternative non-spatial representation: Spatial representations, such as maps or virtual environment simulations require human spatial reasoning skills, which may hinder access by all users.

Abstract Low-Level Information of Home Control: Application interfaces must abstract low-level details, highlighting information and simplifying home management and control. It must provide high-level interaction, e.g. users must interact with elements that group information and specific resources.

Provide Policy Management in "Natural" Approach: If a solution provides policy management, provide user interaction in the most "natural" way possible, in a way that does not seem like programming software. Practical alternatives to aid in this process may include graphical elements usage, such as figures, natural language and gestures.

Enable Simple and Complex Tasks Accomplishment: The solution design must account for people with different goals and levels of "mastery", i.e. for both beginners and advanced users, to access basic or complex functions, through mobile interface. Some possible alternatives include configuration features and interface levels (e.g. beginner, intermediate and advanced) based on users usage and knowledge.

Provide Several Forms of Interaction: Thus, people with no ability to interact through a certain form of interaction might use another one to accomplish tasks. Mobile devices provide several features, such as audio, voice and sensors, which enables designers to go beyond the GUI.

Provide a Dynamic Interface, Decoupled from System Functionalities: Provide a dynamic interface, which reflects changes, such as new appliances and floor layout. New appliances might bring new functionalities. Different vendors might implement functionalities differently. Decoupling would hide these details from users and provide them with a unified interface that adapts to changes. This interface should allow users to modify interface elements, such as identifiers and icons, as well as to insert new images (e.g. regarding new appliances inserted into the system).

Promote Individuality on Interface/Interaction: Provide features to enable users to personalize some interface elements and interaction with system. Thus, solution matches the user's interests, reflecting their individual characteristics and personal relation with the environment, attempting specific and personal needs. Saving user preferences, routine actions and setup values may contribute to personalize interface/interaction and reduce manual repetition in mobile devices.

Consider Privacy on Environment, Device and User Context: The solution design must consider privacy regarding domestic space, the context data captured from both, environment and mobile device, as well as personal information provided by users. Some alternatives include consent and setup features, and all information under this context regarding personal values must be considered.

Provide Internationalization and Localization: The mobile application for home control must provide internationalization and localization, supporting translation of interface elements to another idiom.

4 Discussion

Differently from other works (e.g., [40,41,45,46]), this paper focuses on HCI challenges for the specific domain of home control via mobile devices. Some works expose HCI challenges for mobile devices [40,41,45]. However, these challenges only cover issues related to device characteristics and do not take into account the use context of such devices, e.g. home control. Likewise, works presenting challenges for home automation [46] only address challenges regarding the domestic context and do not consider restrictions relevant to mobile devices. This work addresses both concerns under the perspective of diversity, presenting identified challenges and relating them with literature solutions.

The set of guidelines presented in this paper requires substantial interpretation by designers, which might be considered a drawback. Furthermore, the guidelines were not experimentally validated, and only reflect knowledge and intuition on the specific subject. However, we chose this format because our goal was to provide a high level support to designers in this specific domain, supporting them to consider and reflect upon relevant points which might minimize or overcome the challenges identified in this work. As our literature review has shown, interaction design of domotic environments is a relatively new area. Once we gathered more empirical data of designing and evaluating systems in this domain, the guidelines might be refined and made more operable defining more concrete recommendations or success criteria.

Although the problem domain of home control includes terms such as smart home, most of the found literature focused on home automation. Therefore, it is important to stress that this paper do not focus on specific issues regarding ubiquitous computing [47]. Furthermore, despite recent advances concerning mobile devices, many solutions still lack usage of new forms of interaction. Most of the state of the art solutions still provide interaction through traditional GUI and several works do not consider HCI aspects. Nowadays mobile devices present a huge impact in users' everyday lives, thus new mobile interfaces and interactions are expected to improve users' experiences. Identifying challenges in this context is the first step to tackle them and provide a better interaction.

5 Conclusion

This paper has presented the state of the art and HCI challenges in solutions for home control via mobile devices. The contribution of this paper is to summarize current literature solutions considering HCI aspects and identify challenges under the perspective of diversity, contextualized to this specific domain. In addition, we propose a set of guidelines, which may guide the design process of new mobile applications focusing home control. Our goal is to support designers to consider relevant points highlighted by the challenges and to minimize or overcome them.

Future work will involve a design, implementation and evaluation of app to control household appliances following the proposed guidelines. Furthermore, research about other forms of interaction with mobile devices for this context is required in order to extend the usage possibilities and attend user and situation diversity.

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