A Universal Design Method for Adaptive Smart Home Environment

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Abstract. Nowadays to design a product able to adapt to end-users with different needs and abilities it is necessary to manage a multitude of information coming from the analysis of different context of use. This means that we have to handle parallel and interdependent UCD multiple process. This research aims to define a methodology, which may apply this philosophy into design practice. In particular, it aims to provide tools to summarize the information needed to analyze user characteristics and needs, allows the designer to extrapolate the user's needs and support the selection of prototype technologies suitable to the user categories.

Keywords: Universal design · User centered design

1 Introduction

Universal Design (UD) addressed in this document is defined as "The design of products and environments to be usable by everyone, to the greatest extent possible, without the need for adaptation or special design" [1].

Its application requires conscious effort and awareness to consider the widest possible range of end-user requirements throughout the development cycle of a product or a service. The result of a UD design process should not be considered as a single project, but as a design space populated with appropriate alternatives to the specific characteristics of each user and context of use. In order to make the product easy to use, the adaptive features approach, based on ad hoc manner knowledge, is necessarily needed. A primary aspect of researching and developing adaptive system is to try and understand the behavior of those using the system itself. Being able to comprehend varies types of behavior gives us the basis to form strategies to adequately, effectively, and even adaptively aid user of the system [2].

Nowadays to design a product able to adapt to end-users needs and abilities it is necessary to manage a multitude of information coming from different context of use's analysis. This means that we have to handle parallel and interdependent UCD multiple process. To exhaustively define the project requirements is therefore necessary: first, systematically organize the information coming from the contest of use

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analysis, last but non least, synthesize the information so as to translate into design specifications, intelligible for the designer. Furthermore, to successfully implement a UCD design process, solutions must be tested. User involvement includes choosing appropriate prototyping technologies in the final evaluation. This ensures the prototypes accessibility so as to allow to perform the product analysis, depending on the user's class target identified.

This research work aims to define a methodology which may apply this philosophy in the design practice. In particular, it aims to provide tools to:

- Summarize the information needed to analyze characteristics and needs of all potential users;
- Provide a tool that allows the designer to extrapolate the users' needs and expand the product's performance in all possible contexts of use.
- Provide a method to support the selection of prototype technologies suitable to the user target categories.

2 Research Background

Universal design (UD) is the main method by which designers provide their products and services to be used by the widest possible audience, independently of age or ability. Initially defined by Mace [3], UD was conceptualized by a team of researchers organized in the Center for Universal Design at North Carolina State University, with the publication of the Principles of Universal Design [4]. These principles represented a tool by which determine and evaluate the usability of designed elements:

- Principle 1: Equitable Use
- Principle 2: Flexibility in Use
- Principle 3: Simple and Intuitive Use
- Principle 4: Perceptible Information
- Principle 5: Tolerance for Error
- Principle 6: Low Physical Effort
- Principle 7: Size and Space for Approach and Use

Each of these principles was then expanded in a set of guidelines [4] in order to guide the design process, to permit systematic evaluation of designs, and to help in educating both designers and consumers about the characteristics of more usable design solutions [5]. The principles are a first attempt to articulate a design method that embraces human diversity. These offer only a starting point for the UD process because they cannot analyze operation tasks and user requirements in detail.

To focus on user requirements, Cooper proposed a method that introduced the 'personas' into design process [6]. Personas are abstractions of a groups of real consumers who share common characteristics and needs. The introduction of personas allows product design teams to focus on the real needs of the target customers. Instead of talking about general 'users', personas bring the target consumers to life and help to integrate their needs as a central driver of design processes [7]. Goodwin has defined another method to help the designer in the definition of user profile [8]. He has utilized

direct examination of users and their activities with different objects in a real ambient, and semi-structured interviews. By this, the designer can get a good understanding of the needs of the user.

Other researchers have developed methods to support the definition of the design solutions through the user task analysis. 'Hierarchical task decomposition' method [9], 'task-action grammars' method [10], and 'task-based design' method [11] have been developed and represent some example of the task-based design methods. These methods permit to the designer to decompose the user tasks in various levels and obtain an hierarchical structure of task. Sangelkar et al. [12] have proposed a method based on function-based approach. This method allows to highlight the differences between a universal and non product, through the graphical representation of action-function diagram. This formal user-product representation facilitates the design of universal products and the associated data management and collection.

However, these methods exclude the possibility to diversify and to represent design alternatives for the same task. The design outputs derive from only a specific instance of the design parameters, and they are outcome of a single task-based structure. Savidis et al. [13] have proposed to introduce on the hierarchical structure of design process, 'polymorphic task decomposition' as an iterative phase through which abstract design patterns become specialized to represent concrete alternatives suitable for the designated situations of use.

All methods analyzed are focused on only specific applications or product domains. Our work had been focused to create a new method in which designers could manage and use the all information about universal design in a more systematic way.

3 Proposed Method

Four iterative steps characterize the proposed approach, according to user-cantered perspective [14]: (1) context analysis; (2) definition of design solutions; (3) prototyping; (4) evaluation (Fig. 1). Context analysis consists of three interdependent activities: User Analysis (UA), Ethnographic Analysis (EA), Benchmark Analysis (BA) of available smart technologies. UA and EA respectively provide the definition and the collection of all information about end-user attributes and environmental and social factors, which are relevant for design purposes.

The output of UA consists in the definition of user target categories profiles and in their explanation through the definition of Personas [15]. To define the user profile, and in particular its abilities depending on its own physiological and psychological skills, we propose to use the International Classification of Functioning, Disability and Health (ICF). The EA consist of a user behavior analysis [15] and allows to identify the user actions which is necessary to support, according to the user profile defined in UA and on the available technology analyzed in BA. Moreover, the result of EA allows to refine Personas, and consequently the results of BA, in an iterative way.

Benchmark Analysis (BA) provides the collection of information related to the characteristics of suitable technologies (e.g. costs, flexibility, etc.) related to potential applications (e.g. safety monitoring, health and assistive application, interaction and

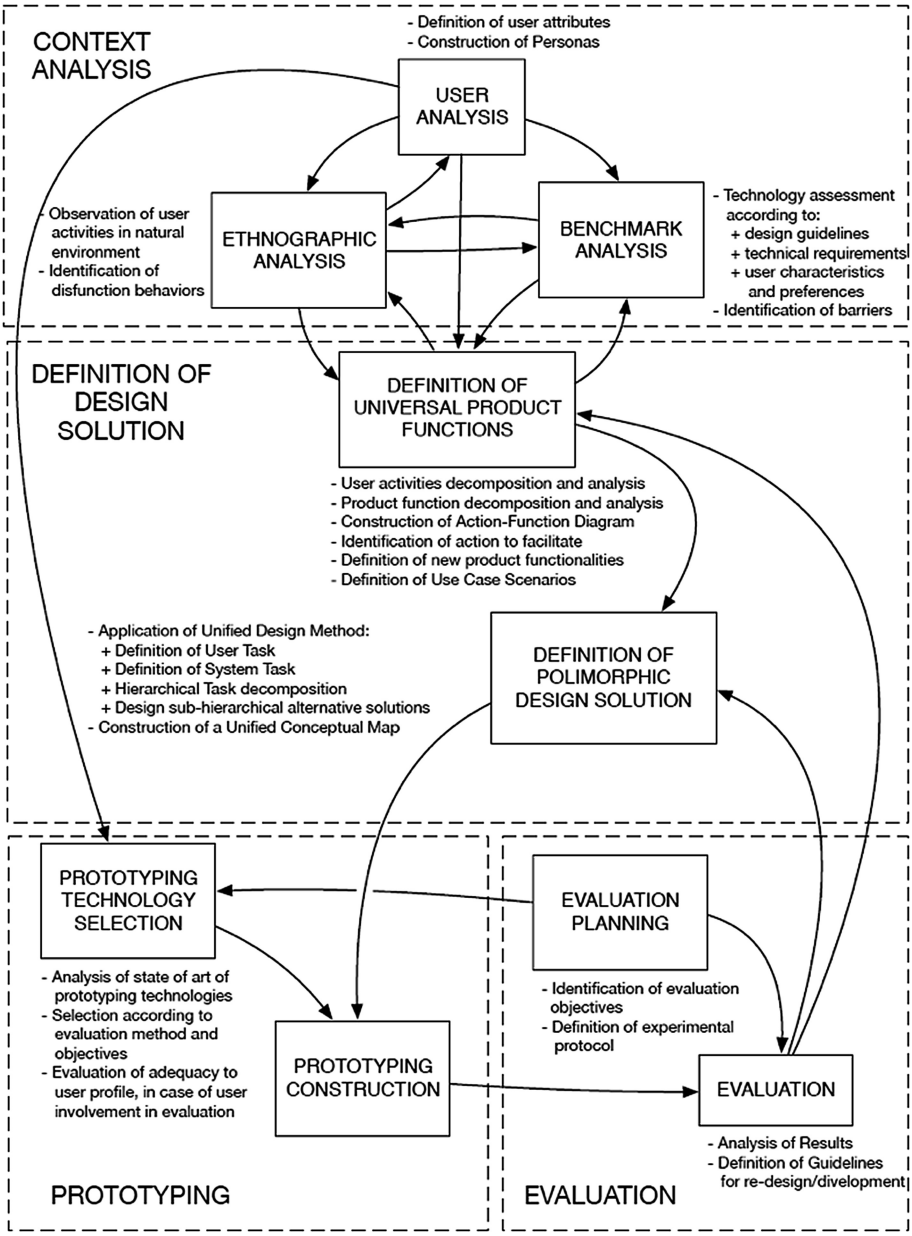

Fig. 1. The propose universal design process

communication, etc.) and aims to assess them in order to select the most adequate ones according to the design objectives. The evaluation is based on a Quality Function Deployment approach [16]. It takes into account design guidelines, technical requirements and user's characteristics, needs and preferences identified thanks to UA and EA.

The Design activity starts from the definition of the Universal Product Functions (UPFs) and ends with the definition of polymorphic design solutions.

In order to synthetize the knowledge acquired thanks to context analysis, we propose to use Action-Function Diagram (AFD) [12].

AFD allows representing and analyzing how a particular user interacts with a product/system/environment, according to his/her own capabilities. It is based on the Functional Modelling approach [17]. This research has developed a formal taxonomy which defines human flows in terms of the Body Functions and the Activities related to Mobility described by ICF. In this way AFD allows to represent the design context in terms of actions to be supported and to correlate them with system functionalities. The identified UPFs are explicated by defining use case scenarios.

In order to support the system design, which implements polymorphic solutions able to support different target user categories in different context of use, we propose to apply an approach based on the Unified User Interface Design Method. This method is able to support the definition of a "space populated with appropriate solution, along with their associated design parameters (e.g. user-and usage context, attribute values, etc.)" [13]. It stars from the definition of User Task (i.e., what the user has to do) and System Task (e.g. feedback, adaptation functions, etc.) and proceeds through a hierarchical task decomposition process until the design of sub-hierarchical alternative solutions.

In order to manage the output of such design process, we propose the implementation of a Unified Conceptual Map, which allows representing the relationship between User and System sub-task as well as the respective polymorphic design solution and the output data, which are necessary to manage adaptation functionalities.

Prototyping Construction is fundamental in order to assess design solutions. The Prototyping Activity starts with the selection of appropriate prototyping technology, according to method and objectives.

Finally, Evaluation is carried out in order to investigate the design process results and define guidelines for improvement.

4 The Case Study

The method here described has been applied to design a smart kitchen environment, providing support to three target user categories in cooking and kitchen management activities

4.1 Personas Method

To communicate the end-user's capabilities and needs to design team, so to encourage designer empathy and support identification of the main functionality that the system should have, the Personas method is used. The Personas method is a plain and effective tools to gather the strengths and objectives of the user profile for designer and developer. Through this method, according to data gather thanks to ethnographic analysis, we have defined three different target user categories: subjects with cognitive

impairment, with dexterity problems and visually impaired. For each profile, we have identified: background, needs/limits, behavior and targets. For instance, the first identified profile, is reported in the figure below (Fig. 2).

	**Background**	John is a former metalworker, retired since 15 years ago. John is a widower and takes care of the housework and home activities. After his wife's death he has entered into a depressive state that partially compromises his cognitive status which includes degradation to maintain a good level of control and environmental organization in addition to an isolation form. His son lives far away and cannot effectively take care of his father daily needs.
Name: Mario	**ICF Profile**	• B(210-229).1 • B144.2
Age: 74	**Needs/ Limits**	• Initial cognitive impairment that prevents the use of common household appliances • Lack of knowledge and technology ability
Profession: Pensioner	**Aptitude/ Behaviour**	• The sense of inadequacy led him to not take care of himself and of his domestic environment
	How we can help	• Support independent living

Fig. 2. Example of defined personas

4.2 System Functionality

The kitchen environment chosen implements a home automation system able to detect and learn the user's behavior and to help him/her accordingly, through an adaptive user interface (Fig. 4). The interface is one of the most important modules of the entire architecture; this enables the system interaction and communication with the user. The Interface structure can be summarized in the following two aspects: graphic features, basic, i.e. standard features uniquely related to a disorder (color blindness, visual disturbances, etc.), and advanced features that represent all dynamic features about adapted interface items according to specific residual function consequent to a specific disorder and they are designed on a single user. Contents represent all interface items editable according to user's actions and the user acts on the interface with his own preferences and needs.

To this end, the interface supports the following functional areas:

- Meal preparation support: meal preparation will need information from refrigerator's food, user's profile and recipes.
- User interaction-appliance support: the system provides the ability to access the appliance control enabling the latter to set up, launch and monitor a given program.
- Environmental Comfort

In order to define the adaptive functions exhibited by the system, they have been defined various use cases.

This paper focuses on the user's interaction- appliance support, the oven in particular.

4.3 Project Interface Concept and Paper Prototype Implementation

A Unified Scheme Functional (SFU) was chosen, in order to manage the information needed to design the interface concept. It allows to represent in a single scheme, and in a simple and intuitive design, the entire of design space. Also the SFU is used to represent the full set of design variations depending on user's attributes and parameters that regulate adaptation mechanism. To this end, the SFU scheme is represented by five important points: the user actions (user task), the system actions performed by the system itself in order to provide the appropriate information to the user, the interface variants (physical alternatives) and services (Interface functions) that are associated with each user profile, at last, the adaptation and data management. The dynamic interface is represented by the subsequent follow:

- Logical and temporal follow, to connect user's action;
- Adaptation flow, to manage the adaptation mechanism;
- Data flow, to regulate data management.

The SFU defines all the interface design specifications, also it is used to manage the complexity in the development phase, so as to ensure compliance with the different projects specifications.

With the aim to support the end user to set cooking program execution two different modes of information presentation were assumed: using a common menu (Normal Setting) and through setting driven (Wizard Setting) process. The Wizard mode is designed to accomplish the task and minimizing the amount of information that the user should understand and manage. Consequently, this solution is suitable for users who have not familiarity with technology and/or have some cognitive dysfunction.

On the other side, the Normal mode, is designed to support user without cognitive dysfunction and characterized by a good technology attitude. Figure 3 shows the first menus screen concept, "Management Oven" in the two information channels.

As one can observe, during interaction with the interface, the user can change the information presentation mode by tapping on the proper button. Each transition from

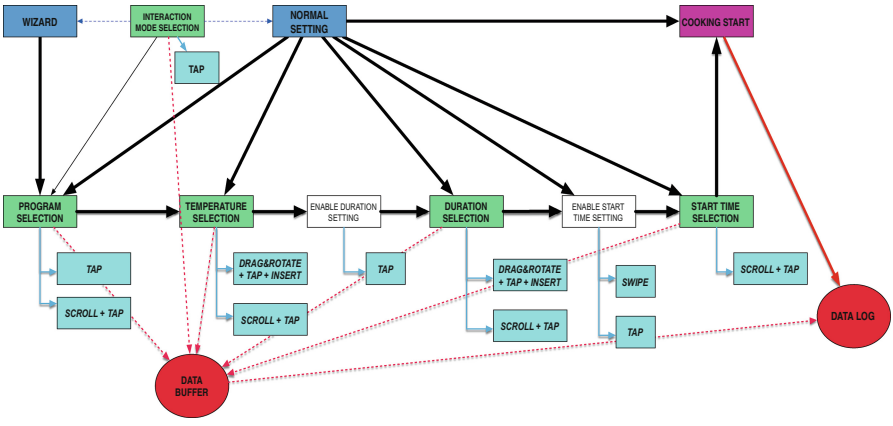

Fig. 3. A oven Unified Scheme Functional (SFU)

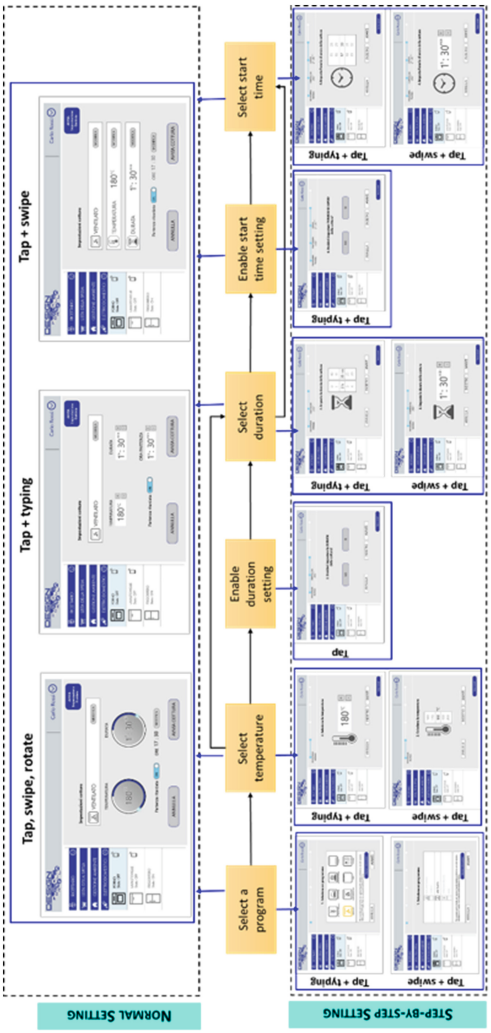

Fig. 4. The smart kitchen user interface: Example of polymorphic solutions related to oven functions.

one information mode to another is recorded by the system; the data collected are used to manage the interface's adaptive behavior.

In detail, when the probability of default mode information exceeds a certain threshold, the information mode presented by default for that specific user is changed.

To ensure access controls, depending on the motor skills and user's preferences, three different methods of interaction have been provided: (1) Tap-swipe-rotate; (2) tap-swipe; (3) tap-typing (Fig. 4). Depending on the user preferences, acquired by the system in the profile phase acquisition, the system will provide a specific interaction mode. To complete the "setting a cooking program" task of the oven, the user must perform the following tasks:

– Select a cooking program
– Select a program temperature
– Select a cooking time
– Select a start time

4.4 Heuristic Evaluation and Accessibility Test

A heuristic evaluation is a usability inspection method for computer software that helps to identify usability problems in the user interface design (UI) [18]. In particular, this evaluation was conducted using Jakob Nielsen's heuristics [19]: visibility of system status, match between system and the real world, user control and freedom, consistency and standards, error prevention, recognition rather than recall, flexibility and efficiency of use, aesthetic and minimalist design, help users recognize, diagnose, and recover from errors and lastly help and documentation.

A team of five experts with the following profiles conducted evaluation: two geriatricians, two psychologists and an expert in human computer interaction. Results, which are reported in the table below, highlight that the propose solutions are suitable for all the considered profile (i.e., profile 1, cognitive impairment; profile 2, dexterity problems; profile 3, visually impaired) (Table 1).

Table 1. Results of heuristics evaluation

		Profile 1	Profile 2	Profile 3
Nielsen's heuristics	*Visibility of system status*	Excellent	Excellent	Perception Problem
	Match between system and the real world	Excellent	Excellent	Excellent
	User control and freedom	Excellent	Excellent	Excellent
	Consistency and standards	Excellent	Excellent	The difference in the interaction mode (tap, swipe and rotate) could generate user frustration
	Error prevention	Excellent	Excellent	Excellent
	Recognition rather than recall	The amount of information about each program are probably too much to be correctly manage	The knob, used for oven temperature and duration changing, may not be intuitive for a inexpert user	- The knob, used for oven temperature and duration changing, may not be intuitive for a inexpert user - Some items may not be seen by the user
	Flexibility and efficiency of use	Excellent	Excellent	Excellent
	Aesthetic and minimalist design	Functional Design	Functional Design	Functional Design
	Help users recognize	No, there is no way to check for an error, but you can cancel any action.	No, there is no way to check for an error, but you can cancel any action.	No, there is no way to check for an error, but you can cancel any action.
	Help and documentation	Excellent	Excellent	Excellent

Related to "Recognition rather than recall" heuristic, the same minor usability issue has been identified for Profile 2 and Profile 3: the knob, used for oven temperature and duration changing, may not be intuitive for a inexpert user. Such problem may be solved by adopting a different interaction modality. In addition, for Profile 1 a relevant usability issue has been detected, as the amount of information about each program are probably too much to be correctly manage: this can be recover improving the wizard.

5 Conclusion

A methodology to support universal design of interactive products has been presented, which provides tools to summarize the information needed to analyze user characteristics and needs and allows the designer to extrapolate the user's needs and select of prototype technologies suitable to the user categories. It exploits Personas and implement a design approach based on functional modeling and on the Unified User Interface Design method.

This method has been used to design an innovative smart adaptive interface to support user with several disabilities (i.e., motor, cognitive, visual) in cooking tasks.

A preliminary expert evaluation, based on Nielsen's heuristics, was carried out to assess usability of the conceptual solution. Results highlight that the propose solutions are suitable for all the considered profile and allow to define design guidelines useful for improvements.

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