A Conceptual framework for Adaptive User Interfaces for older adults

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***Abstract*—Nowadays, information and communication technologies (ICT) have become part of our everyday life, enhancing the quality of life and promoting new forms of social interaction. Despite the numerous benefits of ICT, older adults still present low rates of ICT adoption compared to other population segments. The lack of accessible User Interfaces has been identified as a major barrier. Traditional User Interfaces follow a design for all approach, typically ignoring the needs of older adults. Recent research in Human-Computer Interaction (HCI) proposes adaptive User Interfaces to suit the individual users abilities. Nevertheless, most of the existing approaches perform adaptation based on user profile groups and do not provide personalized adaptation in real-time. This paper introduces a conceptual framework for developing *real-time* adaptive User Interfaces. The system aims to target most common issues among older adults, *i.e.* cognitive decline and vision loss. The developed conceptual framework also presents novel strategic techniques to assess cognitive load and vision related issues in an unobtrusive manner for the user.**

I. INTRODUCTION

In recent years, the world of information and communication technologies through Internet has gradually been integrated in the daily life of older adults. Evidence claims accessibility to technology as a key factor to reduce the risk of social exclusion, access to health care and wellbeing [13]. Despite the number of potential benefits, the usage of such services is very dependent on the interface technology. Usability problems often limit the usage to certain segments of the population. Compared to young generations, older adults have restricted vision/hearing abilities [20], [9] posing huge usability challenges and causing higher resistance of technology acceptance [16], [18], [19]. The rapid growing of complexity of User Interfaces associated with digital literacy issues have a high impact on the low rates of technology adoption among the older adults cohort. In addition, conventional User Interfaces are still designed in a ”one-size-fits-all” manner that ignores all the accessibility requirements of older adults [25], [33]. Many older adults are not cognoscente with modern technology, consequently future interfaces must consider simple yet effective approaches to address usability issues [26]. The lack of technology use among the majority of older adults is also significantly affected by ageing related issues, in particular, the decline of cognitive and vision functions [13]. This decline varies widely between individuals and over the time [15]. Consequently, older adults are unable to effectively interact with digital technology due to difficulties to perceive and manipulate the different elements of User Interfaces.

Despite the advances in assistive technologies to improve the usability and accessibility of User Interfaces, there is still a gap in how to handle the differences among each user [28]. In that sense, the current research is investigating on Adaptive User Interface (AUI) to provide tailored assistance to the user. The aim of an AUI is to improve the interaction between the user and User Interface by adapting aspects as the system layout distribution and available actions, according to the users current goals and needs. Yet, most of the approaches so far explored, do not provide real-time adaptation, but mainly adaptation based on user profile groups [33].

In this paper, we present a conceptual design for developing a real-time AUI system that is implemented as browser plug-in for a web based application. The system is built over an infrastructure prepared to deliver automatic adaptations of User Interface in run time suiting the unique users' needs and abilities. Here, it is depicted how this infrastructure behaves during all the processes starting from the user data gathering until the generation of adaptation of User Interfaces.

In this work, our contribution to AUI research is focused on two major aspects: (i) cognitive load related to the complexity of the User Interface, and (ii) issues related to vision loss that may affect the overall user experience. As such, we present two strategies to assess useful metrics on cognitive load based on pupil dilation measurement; and usability issues related to vision loss, by estimating user distance to screen. Moreover, we present in our conceptual design, a real-time adaptation engine that makes use of these metrics to improve the usability of the interface.

The paper is organized as follows. Section 2 presents an overview of existing solutions and related work on adaptive interfaces. Section 3 introduces the use case scenario and presents the adaptive User Interface model. Finally, Section 4 includes the conclusion and suggestions for future work.

II. BACKGROUND

This section is divided into two subsections: the first describes cognitive impairment and vision loss problems with regard to User Interfaces; the second presents an overview of some existing projects in adaptive User Interfaces.

A. Cognitive Impairment and Vision Loss

The complexity of User Interfaces represents a major obstacle to usability. The problem is further exacerbated when combined with cognitive impairment affecting the way users perceive the complexity of the interface. To tackle this problem, we aim to assess the level of cognitive load in order to identify whenever the user is having difficulties in interacting with the interface. According to the Cognitive Load Theory (CLT) introduced by John Sweller, cognitive load is distinguished into extraneous and intrinsic [36]. These two types of cognitive load are related to the manner in which the information is presented and the effort of absorbing that information respectively. CLT has been widely studied in the fields of education and instructional design in order to predict the cognitive load inferred by different learning materials or interface designs [14], [27], [2]. By comparing the indexes of cognitive load, it is possible to define which material or design suits better the student. Despite CLT has mainly been applied in the context of education, we consider that it might be very useful for AUI research field in order to reduce the extraneous and intrinsic cognitive load of older adults while interacting with User Interfaces. In literature, the methodologies for measuring cognitive load has been distinguished into three categories such as i) subjective measures, ii) dual-tasks measures and iii) physiological measures. *Subjective measures* refers to the assessment of cognitive load by directly estimating the task difficulty through making the user self-evaluating his cognitive process and mental effort required for task performance [3]. The multidimensional scale for subjective measurement provided by NASA Task Load Index has been widely used by many authors to assess cognitive load [32], [7]. Despite subjective measures (e.g. questionnaires, surveys...) are very easy to manage and analyze, they cannot meet the run time requirements of adaptive systems as well as in case of the user's cognitive state is very limited the accuracy of the subjective measures might be influenced. *Dual-task measures* is commonly used in the aircraft field [10], [29]. The basis of this approach is that human processing resources are limited and sharable between tasks concurrently performed. This means that more resources are allocated in a primary task and less resources in a secondary task decreasing its performance. The cognitive load is assessed by measuring the secondary task performance, for instance, during an aerial exercise (primary task) it is requested to the pilot to respond to an auditory stimulus (secondary task). The time he takes to react to the auditory stimuli serves as an index of cognitive load. Dual-task measures is one of the most accurate methods, however is highly intrusive for adaptive interface systems as it has influence in the performance of the primary task. The *physiological measures* category refers to an attempt to correlate cognitive load variations with physiological body responses.

In the literature it is possible to find many physiological measures that serve as indexes of cognitive load such as muscle tension, pupil dilation, heart rate, blood pressure and neuronal activity [24]. In [1] is presented an extensive review of each physiological measure. Pupil dilation is one of the most promising techniques where researchers make use of an Eyetracker to collect data on pupil diameter and perform correlations with cognitive load. The main advantage of this technique is its unobtrusiveness as the user does not need to wear or be in touch with any measurement equipment [30]. A large number of studies have confirmed that in task evoked pupillary responses (TEPR) it is possible to observe an increase of pupil diameter with an increase of task difficulty [5].

Along with cognitive decline, vision loss issues represent the major challenges when it comes to older adults and accessibility requirements for User Interfaces. In this work, we target moderate visual impaired people because few attention has been placed to address their needs. In the literature, most of the existing accessible applications for visual impaired people are concentrated on blind people. Those applications for blind people aim to read textual content that is displayed on the computer screen [23]. Recently, magnifier applications gave an important contribution for accessing User Interface for moderate visual impaired people. However, these applications present only a fraction of screen at time reducing efficiency for location and reading information. [12]. In addition, the user is forced to define specific devices settings to suits his abilities. An exception to this non-adaptive paradigm is presented by [37], where the system can dynamically infer the user visual capabilities based on the screen to face distance technique. Using this inferred knowledge, the system can make decisions over different User Interface patterns to suit the users' needs. A different approach was suggested by [21], that studied the user behavior interaction on an interface with different icon sizes, colors and backgrounds, which showed that cursor movement time and velocity might be used as an index of vision loss.

B. Existing solutions in Adaptive User Interface (AUI)

Recently, a variety of solutions have been proposed and implemented to combat the problems the older adults face while using the ICT devices. Most of the work followed a static approach where the software provides functionalities which allow users to perform the system adaptations by themselves. This approach requires additional training skills and learning which makes the system unsuitable for older adults.

There have been solutions developed to apply adaptations to Web content and also to the applications itself such as the IBMs Web Adaptation Technology, which allows changes to system accessibility settings, for example to increase the text size based on detected user problems and on the request of the user itself [31]. Accessmonkey [6], a common scripting framework was developed to improve the accessibility among the web users. In order to increase the user efficiency when interacting with interfaces, an innovative virtual assistant system named CogniWin [17] has been developed to provide personalized support to the user in case of detected problems when working with a PC. The system uses an Eye tracker, an intelligent mouse integrated with multiple sensors (to measure skin conductance, pulse and applied pressure) and a contextual recorder software module to measure physiological parameters and user behavior. However, little attention has been placed on research on adaptive solutions to improve the accessibility and usability of User Interface regarding the unique needs of each individual. The Avanti project tries to address this problem by providing different interaction modalities for disabled people in web-based information systems. The system also offers different interactive views based on users preferences, skills and requirements. It makes use of adaptable and adaptive techniques to ensure that the system is capable of performing adaptations during the initialization of interaction as well as in runtime. The system specially focuses in motor-impaired and blind user, failing to meet the requirements for moderate visual impaired people and people with cognitive decline which is most common among older adults [35]. The MyUI project proposes an AUI for interactive TV and mobile devices [11]. The system is capable of recognizing the most suitable interface components and elements according to the users needs and context. The target users addressed by MyUI are people with disabilities typically associated with age related issues and stroke. Despite the system meets the critical accessible requirements for older adults with cognitive decline and vision loss issues, the user cognitive state is only assessed over cognitive games which is not a suitable technique for instantaneous adaptive system. Other existing AUI systems are originated from the APSIS4ALL and ASK-IT project [8]. These projects aim to allow older and disabled people to personalize Public Digital Terminals (PDTs) in order to suit their preferences and needs. This personalization is accomplished by making use of Radio Frequency Identification (RFID) and 2D Barcodes technology to easily personalize the PDT interfaces, overcoming the access barrier of requiring to the end-user to manually configure the accessibility features of the PDTs. Nevertheless, those adaptations are static where the users are forced to select the most convenient features for themselves.

Our goal is a personalized Adaptive User Interface (AUI), where the system has sufficient intelligence and autonomy to perceive the current cognitive and visual user state and perform decision over adaptations of the User Interfaces content.

III. CONCEPTUAL FRAMEWORK

A. Proposed Methodology

This conceptual design follows a modular approach seizing its extensibility to other service infrastructures. Structure of modules and their interaction with each other in the system is outlined in figure 1.

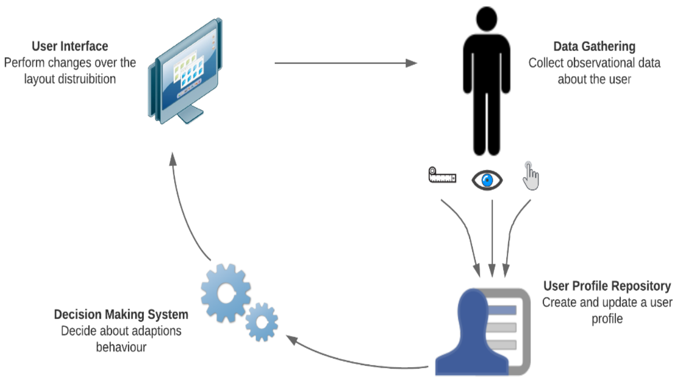
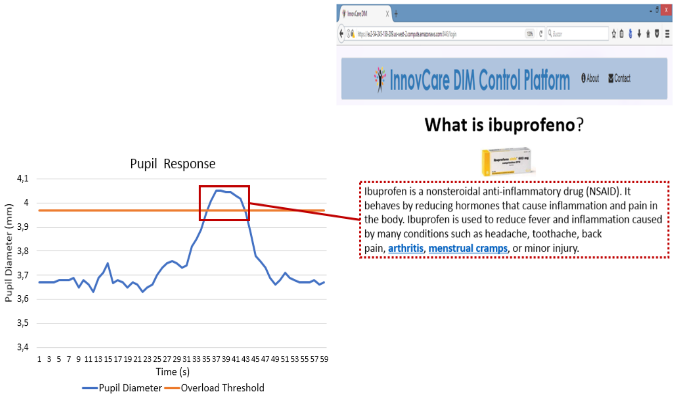


Fig. 1. Architecture of an Adaptive User Interface system

1) Data Gathering module: The Data Gathering module uninterruptedly ”listens” to the input devices to obtain physiological measurements. This module is composed by two submodules that work in separate threads, i.e. a Cognitive load module and a Vision Loss module.

The Cognitive Load submodule processes all the events from the Eyetracker device related to cognitive load. Specifically, it collects data about the users pupil dilation and gaze direction in real-time. It aims to estimate in which area of the User Interface the user is under cognitive overload. For this purpose, the system is continuously monitoring the user's pupil diameter as well as registering the gaze direction. When the system detects large amplitude peaks of pupil diameter, cognitive overload is assumed by the system. In addition, the system correlates this event with the current user gaze direction in order to identify in which area of the User Interface the cognitive overload has occurred, for instance menus, modal windows, text paragraphs etc. Depending on the area of the User Interface as well as the frequency of cognitive overload events, this module classifies the level of *cognitive health* associated with the user. The *cognitive health* level is composed by two main concepts such as Short-term memory and Long-term memory [4]. Short-term memory regards the user capacity to interact with elements that involve reasoning, manipulation and procedural memory (i.e. navigation, reading, information processing etc.). On the other hand, Long-term memory includes the user ability to recall information in order to accomplish a certain task (i.e. remember his password or username). In Figure 2 is outlined a practical example of how this module behaves in a scenario where the user is facing difficulties to understand the information about a medicine. In this situation, the data gathering module is able to detect a peak of cognitive overload in a text element and infer that the user' *cognitive health* is low in terms of short-term memory.

Finally, the information related to the user' *cognitive health* is delivered to the User Profile Repository module in order to update the individual user's profile.



What is ibuprofeno?

Ibuprofen is a nonsteroidal anti-inflammatory drug (NSAID). It behaves by reducing hormones that cause inflammation and pain in the body. Ibuprofen is used to reduce fever and inflammation caused by many conditions such as headache, toothache, back pain, arthritis, menstrual cramps, or minor injury.

Fig. 2. Pupil response to a cognitive overload situation. Followed by the identification of the element of User Interface it occurred.

The Vision Loss submodule follows a similar approach as used in the Cognitive Load module. In this case, the system monitors the user's visual state by estimating the screen-to-face distance. In particular, two different scenarios are taken into consideration when principles of vision loss are detected. Firstly, the detection of steady behavior changes in the user's vision loss aiming to prevent erroneous adaptations of the User Interface. Secondly, the detection of situations where the user is facing drastic changes of visual abilities. In this situations, the system is able to actuate in unpredictable situations for instance in a scenario where the user forgets to wear his eye glasses. Additionally, this mechanism also empowers the system to perform adaptations in the first user session, overcoming an important barrier such as requiring the user to manually configure the system settings to fit his visual needs. Finally, in case the system detects principles of vision loss it notifies the User Profile Repository module to update the user profile.

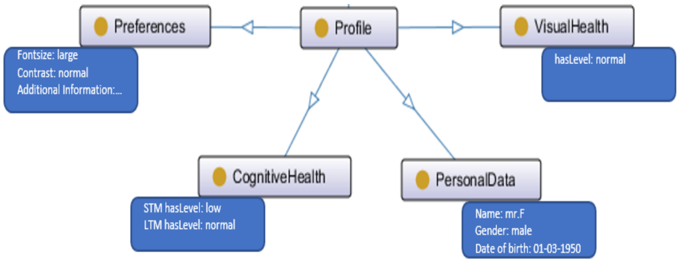


Fig. 3. User Profile ontology example.

2) User Profile Repository module: The User Profile Repository module includes a set of users features that represent the current users abilities, preferences, requirements and personal data [34]. During the user interaction, it aggregates relevant sensor information from the Data Gathering module. The information is then used to dynamically update the user profile. In figure 3 is possible to observe a User Profile example built upon a knowledge driven approach due to its advantages in terms of knowledge sharing, logic inference and knowledge reuse [38]. Following the use case outlined in the figure 2, the data gathering module notifies the user profile module that there is a change in the user Short-term Memory capacity. In its turn, the User Profile Repository module updates the knowledge about his *cognitive health* (ontology class: Cognitivehealth) by changing the level of Short-term Memory to low. The User profile information allow the Decision Making System module to perform adaptations based on the user current abilities (i.e. simplifying complex natural language).

3) Decision module: The Decision Making System module cooperates with both User Profile Repository module and the Interface module. It behaves like a rule-based engine that, based on the current user profile, figures out the decisions about which adaptations will be carried out in the User Interface module. For instance if user short-term memory is low then simplify language, exclude animations, reduce chunks of information. These adaptations have defined specific parameters of CSS Styles or mutations of HTML DOM file to be interpreted by the Interface module. Regarding the content of adaptations that might occur, they were created based on the existent User Interface principles and guidelines. Depending on the user profile, the strengthening of each adaptation might be high or low. For instance, one of the adaptations referred in guidelines for people with vision loss concerns the increase of font size, therefore, the more severe is the vision loss the more will be the font size. The adaptations related to cognitive issues consist in a decrease of interface complexity or activation of assistance features to the user.

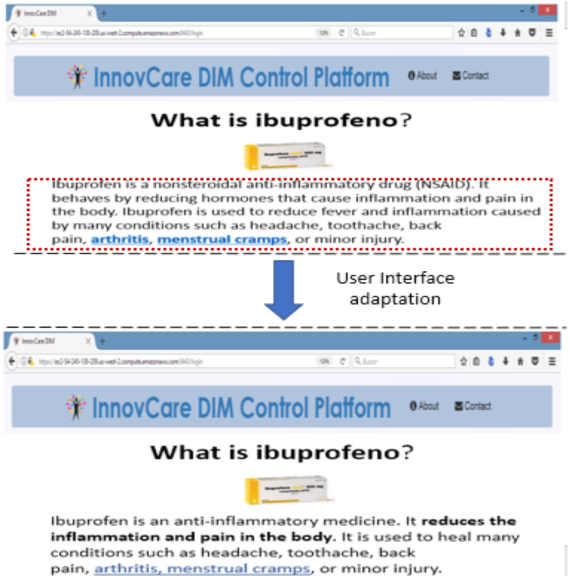


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Fig. 4. An example of User Interface adaptation.

4) Interface module: The Interface module receives instructions from the Decision Making System module about modifications in interface and which layout should be applied. Precisely, it receives new parameters to change CSS style properties (e.g. font size, contrast, color etc.). In case of need to adapt concrete elements of the web page, modification in HTML DOM file may also be executed (I.e. exclude irrelevant elements of the User Interface, simplify language etc.).In figure 4 is outlined an example of an adaptation followed by the use case outline in figure 2. In this specific case, the user is facing difficulties to understand a text element of the User Interface, as result, it simplifies and highlights the text for clear understandability to the user.

B. Data Analysis

The main goal of the system is to adapt the interface according to the user needs. In this regards, the system capabilities to measure the individual current state plays an important role to perform proper adaptations of the User Interface. Considering the topic of this research, we are focused on the measurement of the user cognitive load and vision loss. Both cognitive load and vision loss are continuously assessed by the system in real-time.

Regarding cognitive load, an Eyetracker device is used to collect data for the user's pupil dilation. The system is continuously monitoring the user's pupil responses and when it detects peak amplitudes of pupil diameter between 0.3 mm and 0.5 mm compared to pre-pupil dilation baseline, it is considered that the user is under cognitive overload [5].

A similar approach is used to assess vision loss. The system applies a scoring model to measure screen-to-face distance. Then, the result of that score is statistically analyzed to enable the system to perceive steady and instantaneous change of visual abilities. The screen-to-face distance is estimated using the Eyetracker where a function is applied based on the distance between both eyes and its elevation with respect to the screen [22].

C. An Example use scenario

As a generic case study to evaluate the proposed solution, we target the INNOVCARE Platform which is a web based health platform for older adults that aims to monitor health status and behavior enabling self-management of health and chronic diseases. In this scenario, we integrate our AUI solution in the INNOVCARE infrastructure to improve the accessibility and usability of the system.

In particular, we focus on supporting the user in two different scenarios. One regards situations where during the interaction with the system the user feels confused or cognitively overloaded. We address this issue by identifying and adapting the interface elements that cause difficulties for the user. These adaptations are mainly related to a decrease of interface complexity and notifications with cues to better assist the user. On the other hand, we also address situations where the layout of the User Interface is not well perceived due to visual loss issues; the system is able to infer the current user vision state and to adjust the layout format properly. By this, the system offers a personalized interface, enabling natural and intuitive navigation, resulting in an increase of user performance and engagement with the system.

IV. CONCLUSION

This paper presents a conceptual framework for developing an adaptive User Interface for a web based application. Specifically, we presented a real-time adaptive framework able to detect when the user is facing difficulties in the interaction, in order to react accordingly. Vision loss related problems are detected by monitoring the face-to-screen distance in real-time. Pupil dilation is used as a base metric to detect cognitive overload, possibly due to the complexity of the interface. Finally, these metrics are used to enable a real-time adaptation loop of the interfaces. Although, validation of the approach is still work in progress, the conducted literature review identified some limitations of existing solutions and adopted strategies towards adaptation, that leave scope for further investigation on real-time adaptive solutions. Future work will include a generic solution for web based applications, and the investigation on alternative metrics to be used to assess usability.

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