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LONG PAPER

Providing adaptive smartphone interfaces targeted at elderly people: an approach that takes into account diversity among the elderly

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Abstract The growth of the elderly population in many countries makes it necessary to develop appropriate technologies for them. These include mobile phones, as they are increasingly becoming cheaper and more widespread. Furthermore, many families would like their elderly relatives to use this technology as a means of fostering digital inclusion. However, the current designs for mobile devices software are aimed at a young audience, rather than taking account of the different needs of the elderly. The elderly population can be characterized by their wide diversity which can be attributed to decades of varied experiences. Moreover, this is heightened by sharp differences in acquired education levels, use of technology at work, cognitive skills and physical dexterity. The authors believe that this diversity is even more striking in developing countries, such as Brazil, since in these countries a huge economic gap still exists between different elderly people. This paper seeks to investigate: (1) What can be done to solve the problem of enabling the elderly to use smartphone interfaces and (2) how one should develop adaptive smartphone interfaces that can be targeted to the elderly. With this in mind, this paper shows how a prototyped platform was implemented and evaluated. It is worth stressing that real-life experiments with Brazilian elderly people were carried out. The results suggested that there had been a reduction in the interaction time as well as a significant increase in user satisfaction.

Keywords Reconfigurable middleware · Mobile devices · Tailorable interfaces · Elderly · Evaluation · Framework

1 Introduction

Technological innovations are not just custom gadgets; they are increasingly playing an essential role in the routine of people's lives. The elderly, in particular, who represent a significant proportion of society, can benefit from the use

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of technological innovations [58]. Aging populations are a widespread phenomenon and must be taken into account when designing future technologies and services.

According to the Brazilian 2000 Census, the number of elderly people represented 8 % of the total population, reaching 14.5 million. Ten years later, Brazil had 18 million people over 60 years old, which now represents 12 % of the total population [37]. Age has a strong influence on the ability to use information and communications technology (ICT), which is shown by the fact that a significant reduction in its use can be perceived after the age of 45 [44]. Moreover, research in this area tends to stress the fact that there is a negative link between old age and the users of ICTs [30]. According to the Brazilian Institute of Geography and Statistics [37], this new demographic reality will have to be taken into account when drawing up new public policies. Satisfying the needs of the elderly does not only involve building houses adapted to their requirements and making public transport available, but also allowing these users to be included in the digital age so that they can use technology to improve their lives.

According to Nielsen [50], many elderly people in industrialized countries lead active lives. Although they have usually retired, they have a dynamic life and often show a great interest in modern technology, such as mobile devices. The same analysis shows that 18 % of elderly people use smartphones and that there was a 6 % increase in the acquisition of these devices by the elderly between 2010 and 2011. It is worth noting that in 2006, the Brazilian Computer Society (SBC) listed ten Grand Challenges in Computing Research, the fourth being what was called *Participative and universal access to knowledge for the Brazilian citizen* [4]. In the authors' opinion, the current user interface design does not encourage interactions between members of the general public or take into account the different needs of users, especially those who are not digitally literate. Moreover, there are sharp differences (particularly among older adults) with regard to experience with technology, cognitive skills, education and physical dexterity. Hence, this paper argues for interfaces to be designed that are flexible enough to meet the diverse requirements of the elderly while interacting with smartphones. The myth of the average user has been dispelled [17], and *Design for All* [60] is a reality that must be borne in mind in the projects.

In light of the above, one way to deal with the question of diverse needs is to provide enough flexibility so that user interfaces can be adapted to different organizational contexts, and cater for the preferences and needs of the elderly users [21, 26, 27, 32]. With the aim of clarifying what the authors call *different organizational contexts*, Tables 1 and 2 list the considered types of context and provide an example of one user's context. According to Nielsen [51],

Table 1 Types of context

Variables	Values
Gender	M, F
Age	Older than 60 years old
Education level	Less or more than 4 years
Experience with smartphones	Little or a lot
Vision	Impaired or normal
Physical motor	Impaired or normal

while feedback can make it easier to understand tasks during the interaction with mobile devices, elderly users face more complex problems that involve learning how to carry out basic activities. Being given feedback is often not sufficient to allow the user to complete the task in a satisfactory way [23, 24, 51].

When the interface is more complex, if the user does not understand the concepts of mobile services such as SMS (Short Message Service), the problem becomes even worse. Similarly, the complex hierarchy of menus found in a mobile device increases the difficulty of navigating through its functions. This means the ability to remember the sequence of actions is a key requirement [23, 26]. However, when the target audience is the elderly, the design solutions for mobile software applications should not offer solutions that discriminate between people or cause embarrassment. In that respect, the solutions should rather be flexible, and respect the diversity of the user group, by adjusting to each profile and allaying the fears of the users that arise from their inexperience or lack of knowledge [25–27, 58].

In this context, this paper outlines a proposal for building adaptive/flexible smartphone interfaces targeted at elderly people. It is argued that there exists a considerable diversity among elderly people. This is due to the varied experiences of several decades (e.g., some of them have achieved a high degree of education, whereas others are nearly illiterate). Hence, to address this diversity, there is a need for an adaptive interface that can ensure the required tailorability. To achieve this kind of adaptive interface, an experiment with elderly people while they were interacting with smartphones was first conducted. Their behavior while engaged in this activity was observed in order to determine the key requirements for their satisfaction. Establishing requirements is in accordance with the PLuRaL framework (described in Sect. 4) which states that first of all, the requirements in six distinct areas (social world, pragmatic, semantic, syntactic, empirical and physical world) must be defined prior to implementing the system, and then the OpenCom middleware approach should be followed [13].

OpenCom was adopted because of its runtime re-configurability approach; this ensures that an interface can be

Table 2 Example of one user's context

Variables	Values
Gender	F
Age	68
Education level	More than 4 years
Experience with smartphones	A lot
Vision	Normal
Physical 5motor	Normal

adapted to the target needs and applications. Yet, OpenCom is based on a component approach [62] which means that the components are deployable at runtime whenever required and destroyed when no longer needed. This is particularly important with resource-constrained devices such as a smartphone (e.g., with little memory), as only the required functionalities are deployed in the memory. The results of the evaluated prototype suggest a reduction in interaction time results from the use of flexible user interfaces, together with an increase in user satisfaction.

Finally, to date, a research study that proposes an adaptive interface for smartphones that seeks to meet the diverse needs of elderly people has not been found. This diversity is particularly evident in developing countries such as Brazil, where there is still a wide social gap between rich and poor people. The rest of the paper is structured as follows. Section 2 sets out the problems encountered when the elderly interact with smartphones; it also discusses related work. Section 3 gives a detailed account of an exploratory experiment with elderly people interacting with smartphones, which was conducted to help plan an adaptive smartphone interface design and implementation. Section 4 outlines the design of flexible interfaces through PLuRaL, a framework that has helped the design of flexible interfaces that are capable of adapting to different situations experienced by users. Following this, Sect. 5 describes the design of adaptive smartphone interfaces for the elderly using the PLuRaL framework and discusses implementation issues regarding the prototype. Section 6 provides an evaluation of the prototype that was built following the OpenCom approach, which is particularly well suited to resource-constrained devices (such as a mobile device). Some final remarks and the conclusions of this study are summarized in Sect. 7.

2 Problem statement on how the elderly interact with smartphones

Although studies related to mobile technology have been undertaken for some years [24], the design solutions offered to elderly users still do not fully meet the requirements of elderly people who are interacting with mobile technology [25, 28]. Studies in the literature show that elderly users face problems of accessibility and usability when interacting with mobile devices, such as a smartphone.

2.1 General problems in the literature

Older people experience what is referred to as cognitive aging, a decline in executive function/working memory that makes it harder for them to support self-management [14, 38]. Research on aging shows that this phenomenon causes a general decline in a wide range of cognitive functions, including processing speed, attention, working memory capacity, the ability to learn new information and the ability to retrieve information [3, 5].

It can be argued that the aging population poses a fundamental challenge to HCI because of the need for flexible systems [7, 48]. A survey of related work was carried out to discover the main problems identified in the literature, and those encountered are summarized in Table 3. In the first column, each problem is labeled; in the second column, the types of problem encountered are classified; and in the third column, a description of the problems is added.

Several papers in the current literature describe problems and solutions with regard to the use of smartphones by elderly people. However, much of the work found in the literature points out problems experienced by elderly people in general and does not take into account the wide diversity that can be found among this section of society. On the other hand, some works (e.g., [57, 70]) failed to target the problem of *diversity* directly. Instead, they designed and evaluated interfaces for elderly users with different degrees of computer experience, spatial ability and subjective technical confidence, in an attempt to cater for a more general elderly population. In view of the differences arising from a wide range of contexts [48], one should also be aware of the dynamic nature and evolution of ICTs. Moreover, given the fact that users require time to adapt to the technology, methods and techniques are required for designing, implementing and evaluating interfaces that are tailorable to the changing preferences and needs of the target audience [27]; in the authors' opinion, systems that lack this kind of flexibility can cause user frustration.

A research study carried out by Dewsbury et al. [15] discusses how technology can be designed inclusively for older people in an acceptable way. They examine the issue of design, and how these concerns have been addressed in a series of projects that are aimed at supporting people in the community. In their research, Dewsbury and colleagues developed a system that was usable by people suffering from many of the normal infirmities of old age and which did not look like a conventional computer with all of the

Table 3 Problems of interaction experienced by elderly people with smartphones

Id	Problem	Description
P1	Small icons	The user has difficulty in visualizing the icons [20, 63]
P2	Inadequate labels	The interface employs terms and expressions that are difficult to understand [63]
P3	Menu hierarchy	The user has difficulty in understanding the menu hierarchy [30, 63]
P4	Keys with multiple functions	The user is unaware of the keys that have multiple functions [63]
P5	Automated assistance	The user receives aid without having made a request [63]
P6	Sequence of actions/navigations	The user has difficulty in performing a sequence of actions/navigations [30, 51, 63]
P7	Scroll bars	The user is unable to visualize a scroll bar [30]
P8	Session time	Session time expires too fast [30]
P9	Feedback	Feedback is inadequate or nonexistent [20, 30]
P10	Help	Help is inadequate or nonexistent [30]
P11	Font size	The user has difficulty in visualizing the words [20, 51]
P12	Interface item moves without request	The interface item unexpectedly moves which makes it difficult for the user to interact [51]
P13	Color contrast	Low color contrast during the user interaction [51]
P14	Search	Search is inadequate or nonexistent [51]
P15	Error messages	Error messages with technical terms [51]
P16	Keyboard size	The user has difficulty in visualizing and using the keyboard [20]

misgivings that this entails. This system includes help messages and feedback to improve the interaction of elderly people with computer systems. However, unlike the research carried out in Dewsbury's paper, it is necessary to address other aspects of the tailoring interfaces, for example the size of the buttons, size of the keyboard, font, colors and navigation screens.

The main interaction with the users is through portable devices (for example smartphones). Although touch screens have proved to be of great value for older adults, touch screens on mobile devices are extremely difficult for them to use due to the small size of the targets and this is another drawback with regard to usability [5]. The restricted screen space only allows a little information to be displayed at a time, which means that the amount necessary to be memorized to use the applications increases [10, 34, 65].

Blythe et al. [7] conducted research into the design of emergency health services for the aging population. The design of this technology is currently driven by a medical model of client needs which takes little account of the social context of the home. According to them, the design challenges for HCI are to make this technology attractive, provide privacy, allow informed choice and reduce rather than increase the isolation currently felt by many older people. Also, Blythe and colleagues have looked at the various ways that technology can support independent living, by illustrating individual needs through interviews with older people and the people who deal with those needs. They have examined the physical risks facing older people and their likelihood to occur. However, their research fails to address issues such as the importance of flexibility when defining the needs of socially dependable systems. Socially dependable systems advocated by Blythe and colleagues take account of the social context and the need for sociability; they are accessible to anybody who needs them.

Research into flexibility has highlighted some technical issues, such as the infrastructure required to construct dynamic reconfigurable applications [9, 42]. Other research studies have given priority to specific mechanisms that lead to adaptation, for example icons and menus [43, 55]. Some studies offer guidelines on how to design interfaces for senior citizens [26, 30], while others have investigated the phenomenon in terms of tailorability [46]; these include investigating the reasons that lead users to customize applications [54, 56].

It is clear from the literature that one way to increase user effectiveness, efficiency and satisfaction with an interface in general is through multimodal interaction, such as the use of visual interfaces and sounds [1, 39]. This could be of special benefit to older adults who may feel restricted by having to interact through the use of only one modality and may rely on others [8, 69].

Hanson [29] examines information-bearing components used by younger and older adults. These are considered in terms of the long-term implications of designing interfaces for older users; however, the current problems are viewed as foreshadowing future trends. He conducted two experiments that distinguished between the way younger and older adults carried out tasks that required them to seek information on the Web. Selecting tasks that involved finding information from specific Web sites, it was found that older participants had a poorer performance compared to younger participants. However, in his research, Hanson failed to take account of the users' satisfaction during their interaction with this type of interface.

Vines et al. [66] analyze the findings of a series of participatory design workshops with ten people over 80 years old. The focus of the workshops was new banking technologies for the very old. The participants were asked to discuss their current experiences with banking and were given packs of concept cards which contained design sketches and brief outlines of concepts for new financial services. However, in their research they did not provide a technological solution which could be tried out by the elderly users. This is a solution that would have helped tackle the problems revealed by the senior citizens.

Another factor to be considered to improve usability is the question of how to simplify the information provided to the users [52, 67]. Vague or abstract language (for example "save/next") requires listeners to draw inferences that may be incorrect. Concrete language can thus assist in the understanding of information, and this can be supplemented by the use of visual aids, such as pictures and diagrams to help clarify key points [28, 35]. Similarly, some research studies encourage the design of flexible applications on smartphones for elderly people [25, 53], though do not rely on the implementation and evaluation of adaptive models/tools (i.e., a middleware approach). Other researchers develop smartphones for seniors and carry out generic usability testing with these devices [63]. The authors in [19, 64] have discussed the design of flexible solutions without paying much attention to evaluation. Thus, it can be argued that there are several ways of evaluating interfaces, such as heuristic evaluation [23, 48], although these are not designed for analyzing adjustable interfaces.

2.2 Our proposal for adaptive interfaces

In summary, a naturally supported solution involving adaptive interfaces for smartphones targeted at elderly people could not be identified. According to the authors, this kind of flexibility/adaptation will ensure that a wide range of actors are taken into account and that the requirements of a wide diversity of elderly people are met. This is the key argument of the present research: to insist that diversity is a significant factor among elderly people. This kind of diversity can be attributed to differences in educational levels, cognitive skills and gender. In light of this, one might attempt to define elderly people's requirements while interacting with smartphones. These requirements can be determined (using PLuRaL) and then applied to smartphone interface implementation by means of an OpenCom middleware approach since this establishes runtime reconfigurable systems.

The proposed solution for devising adaptive smartphone interfaces targeted at elderly people is as follows:

- Design phase involves following the definition of the PLuRaL framework for interface requirements to determine functionalities and establish tailorable behavior.
- Implementation phase involves the use of an OpenCom middleware approach [13] for translating the properties (i.e., requirements, functionalities and tailorable behavior) outlined above, into a flexible/adaptive interface targeted at the elderly. PLuRaL has been adopted because it provides valuable guidelines for designing flexible interfaces that can help tailor the interface to the targeted needs. This is crucial since (as argued earlier) it can be argued that there is a wide diversity of needs among elderly people. Hence, an interface for smartphones should also be tailored for the target audience. OpenCom middleware is employed for implementation as it enables functionalities (defined at design time through PLuRaL) to be deployed whenever required at runtime and destroyed when no longer needed. In this way, it can be ensured that the system has less memory and processing overhead (i.e., if a functionality is no longer required the system itself may destroy that component in the same way as in garbage collection). This is particularly important when there are scarce resources such as in the case of a smartphone.

The following section discusses the experiment that was carried out to observe the behavior of the target audience for whom the interface will be built. This refers to how one should start developing adaptive interfaces that are targeted at a particular public domain.

3 An experiment with elderly people interacting with smartphones for the design and implementation of adaptive interfaces

3.1 Overview

One of the key challenges of researchers in human–computer interaction (HCI) is how to provide interfaces that are suitable for the largest possible number of users regardless of their sensory features, or physical, cognitive and emotional properties [25–27, 46, 48, 58]. One way to do this is to develop flexible reconfigurable interfaces in which the functionalities are deployable at runtime (i.e., if one needs an interface with larger fonts, the system can deploy a component with that functionality at runtime without having to stop the entire application). In this way, it is possible to offer interfaces that are tailorable and cater for user preferences and needs while interacting with smartphones. This approach is also supported by [27, 46, 48].

As mentioned above, tailorable user interfaces for the elderly are implemented by employing a framework entitled PLuRaL [2, 47]; PLuRaL was adopted as a reference point to drive the design process. This framework is grounded in the area of HCI and Organizational Semiotics [41, 63] and has a wide range of interaction requirements, including some that are controversial or only of interest to minority groups and are not only those of the users but also derive from different devices and interaction environments. The semantic, pragmatic and social aspects of the interaction are also taken into account.

PLuRaL is organized in three phases [47] (see Fig. 1). The first seeks to clarify the differences between the potential users, devices and environments in which the system can be used. Thus, this stage is intended to clarify the problem and identify possible solutions. The second phase is the formalization of functional requirements; this is undertaken in the domain and includes rules governing the behavior of the users. Finally, in the third phase an approach is adopted that defines the design of flexible interfaces through the formalization of standards that are tailored to the operation of the system.

The need for a flexible interface (and the subsequent use of PLuRaL) is explained further in the section below. This involved conducting an experiment with wide-ranging elderly people (i.e., in terms of their education level) and revealed that there was a considerable difference in their performance while using a smartphone, although they were all elderly.

It can be argued that Universal Design [11] is an approach that is currently being widely adopted. Hence, it is important to design systems that provide access to knowledge and information and hence avoid physical and social segregation [58]. Furthermore, during this research, it was observed that the literature mainly concentrates on the interaction problems faced by elderly users with smartphones. Hence, they fail to take account of the diversity that can be found among elderly people, such as in education, and with regard to their physical and cognitive abilities [58].

3.2 The plans for the experiment, execution and results

A preliminary experiment was carried out with the aim of investigating the interaction of elderly users with mobile devices. This involved a group of ten elderly people between 60 and 84 years old, some with a low level of education and others with a higher level. In addition, experiments were conducted with elderly people with different degrees of experience in the use of technology (as

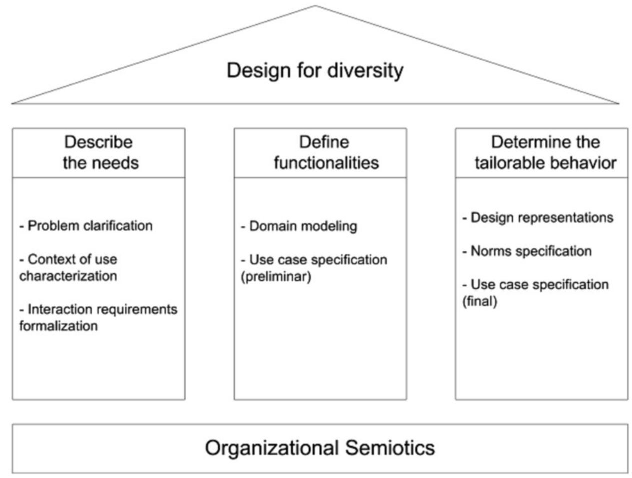


Fig. 1 PLuRaL framework phases [47]

can be seen in Table 4). The reason for this was to show that one cannot construct a single smartphone interface targeted at elderly people.

This section describes the planning and execution, and formalizes the results from the exploratory experiment. These results provided the basis for designing and implementing flexible smartphone interfaces to meet the interaction requirements of an elderly audience.

3.2.1 Planning the exploratory experiment

The goals, hypothesis, methodology, equipment and devices for this exploratory experiment on the way the elderly interact with smartphones are set out below:

Hypothesis Given the questions raised in the literature, it is believed that the wide range of problematic situations encountered should confirm the presence of specific requirements among the elderly which must be addressed when defining the design.

Objective of the experiment To observe and analyze the interactions of elderly users with applications from smartphones and identify usability and accessibility issues during the interaction with the software application in the mobile device.

Applied methodology As a means of analyzing the interaction of the elderly user with applications from smartphones, a group of senior users was invited to participate in a practice session involving the use of the device, as illustrated in Fig. 2. The purpose of the activity was to allow these users to record a contact in the smartphone book and call the number afterward. On the basis of the results of the experiment, it was possible to formalize the interaction requirements in accordance with the PLuRaL framework [47]. This interaction dealt with factors such as the physical design of the device, the impact of

Table 4 User profile

Elderly people Pair ID	Gender	Age	Education level (years of formal study)	Home phone usage	Smartphone usage
P1	F	81	Less than 4 years	Daily	No
	F	84	Less than 4 year	Seldom	No
P2	F	76	Less than 4 year	Daily	No
	F	74	Less than 4 year	Daily	Yes
P3	F	65	Less than 4 year	Daily	No
	M	69	Less than 4 year	Seldom	No
P4	F	66	Less than 4 year	Daily	No
	F	60	Less than 4 year	Daily	Yes
P5	F	62	More than 12 years	Daily	Yes
	F	60	More than 12 years	Never	Yes

this interaction on the real world and the adaptable behavior of a mobile device, with a view to addressing the interaction requirements of elderly people.

Support material The following were prepared for conducting the exploratory experiment: the Free and Clarified Consent Term, the Profile Survey Questionnaire and the Participant Observation Form. The Free and Clarified Consent Term made clear to the participants the purpose of the research, its scientific character and the fact that they were involved on a voluntary basis. The Profile Survey Questionnaire addressed social and cultural issues to define the profile of these elderly users. Finally, the Participant Observation Form was designed to assist in observing the user during the interaction with the smartphone. Apart from the observation form, the participants were also filmed, so that all the details of the study could be analyzed. With regard to ethical questions, this research complied with the recommendations set out by the New Civil Code [18] and Federal Constitution [49].

Devices used The elderly users were divided into pairs and each individual pair had a Samsung Galaxy 5 smartphone with Android operating system release 2.2. The mobile device was charged with a battery and credits to make phone calls.

3.2.2 Conducting the experiment

The exploratory experiment with elderly people and smartphones took place in a Reference Center for Social Assistance (CRAS) in São Carlos-SP (Fig. 2). These users form a part of a group that take part in physical activities for seniors, such as dancing and theater. Together with these activities, ten people were invited to participate in some interactive tasks with a mobile device, which are described in the following section.

First of all, the learning profiles of these users were examined. It was found that those with no formal education either never used the mobile device or only used it to answer calls. On the other hand, users with a university degree or high school diploma were able to make calls, send messages, take pictures and play games on the smartphone. It should be noted that there was one user with Alzheimer's disease.

The participants worked in pairs and each individual had a smartphone (Fig. 2b). During the test, the pair sat side by side during the interaction with the mobile device. Moreover, a sheet of paper was handed out to these users with the name and phone number of a particular person, to save them having to make this contact on the smartphone and then call to the number given. While these users carried out their tasks with the mobile device, the researchers who conducted the exploratory experiment filled in an observation form with questions are given in Table 5.

The elderly were informed that, if necessary, they could help their paired colleague or ask for help during the task. The number was from a landline phone, where the researcher could record a "Thank you message" on the answering machine. Their answers were analyzed to form profiles that took into account their age and level of education. For this reason, the participants with a similar age and educational level belonged to the same group. After the tasks had been completed, the authors had a discussion with the pair on issues relating to interaction and the difficulties found during interaction with the smartphone.

3.2.3 The results of the experiment: a discussion

During the experiment, it was observed that several users had difficulties in interacting with the smartphone. One participant from the P1 pair highlighted the following: "The screen is very touch-sensitive, so it causes a lot of errors and the path to perform the requested task is too long." The sensitivity that the user refers to is the fact that

Fig. 2 **a** Setting of the experiment. **b** Elderly people interacting with the smartphone

involuntary touches on the mobile screen result in unwanted actions.

Apart from the 60-year-old user with a higher level of education, all the other users needed help to perform the task of saving a contact and making a call for it. Moreover, none of them interacted with their paired colleague.

Regarding the size of the screen, one of the P4 members said "It was not appropriate and hindered the interaction." Another user of P2 complained that "The space for the registration of contact is very small, so one only has a general idea of the registration screen." As the mobile device used was a touch screen, women with long fingernails, as seen in Fig. 3, had difficulty in completing their tasks successfully.

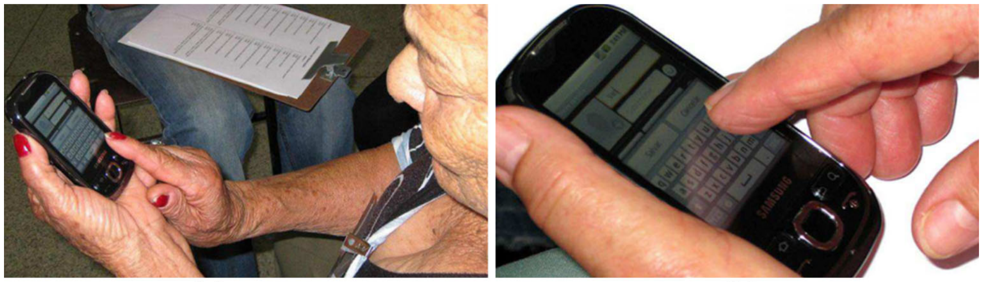
The members of P5 also pointed out that "There should be a standard pattern for the position of the buttons, because it ends up confusing people." With regard to the size of the keyboard keys, all participants felt that it was not appropriate, because there were constant errors. The P4 pair explained that "When attempting to touch a letter or number, one ends up striking the one that is nearest because the keys are too small," as can be seen in Fig. 3b. Furthermore, both P2 and P5 stated that "The keys are too small for our fingers, so we have to repeat an action several times."

Another problem observed in the interaction of elderly people with smartphones concerns the issue of color. Most of the pairs said they did not like monochromatic interfaces. For example, the P2 pair highlighted the fact that "These predominantly black and white colors are difficult to read and do not give due importance to the most important things." The P4 pair noted "The interface should be more colorful; for instance the save button could be yellow and not gray."

Regarding the sequence of actions, it was clear that the P2 pair had a lot of difficulty in following a logical sequence to complete the task. One of them explained that "There are many levels to complete the task." Unlike the P2 pair, that have had no access to education, the participants from the P5 pair, with a higher level of education,

Table 5 Data from the users' questionnaire

Elderly people Pair ID	Did you need any help to start the task?	Is the screen size appropriate?	Is the size of the buttons appropriate?	Is the size of keyboard keys appropriate?	Is the color combination appropriate?	Is the sequence of actions to save contacts appropriate?
P1	Yes	No	No	No	Yes	No
	Yes	No	No	No	Yes	Partly
P2	Yes	No	No	No	No	No
	Yes	No	Yes	No	No	Yes
P3	Yes	No	No	Yes	Yes	Partly
	Yes	No	No	No	Yes	No
P4	Yes	Yes	No	No	No	Yes
	Yes	No	No	No	No	Yes
P5	Yes	Yes	Yes	No	No	Partly
	No	Yes	No	No	Yes	Yes



(a) (b)

Fig. 3 Older users interacting with a smartphone

accomplished the task requested successfully in accordance with the standards set for the action sequences of the devices.

4 Design of adaptive smartphone interfaces for the elderly with PLuRaL

According to Bevan [6] and Henry and Grossnickle [33], it is essential to improve the design process and cater for the needs of older adults to enable them to develop applications that support their preferences and needs. Moreover, it is necessary to incorporate guidelines that handle usability and accessibility for that population [59]. A system created for a specific application needs specific design decisions to handle different needs and functionalities that may be altered during the system's lifetime [22]. The design decisions in this paper were based on existing literature.

Hellman [30, 31] set out guidelines and recommendations for building and evaluating the flexible interfaces of smartphones for older adults. Erickson [16] proposed usability scenarios for each flexibility level (personalization, composition, expansion and extension) and compiled a set of usability and design patterns to help design and implement decisions. Baranauskas and de Almeida Neris [2] selected interaction patterns related to flexible interfaces. Based on their work, the features a flexible interface must incorporate were adopted. Furthermore, when users are used to the system domain and its design, this is reflected in the domain characteristics and assists the interaction [2]. Thus, it is argued that knowledge of the context (who is the user, devices features and environment) and the information about the system domain influence decisions regarding the design of the flexible interfaces.

After the experiments had been carried out, it was possible to see the different interaction needs of this group of individuals. The three pillars of the PLuRaL were applied with the aim of finding solutions that adhere to the premises of the Universal Design [11].

4.1 Pillar I (first phase): definition of requirements

The initial stage of the first pillar of the framework is concerned with defining the interested parties in the system, in terms of "layers," since this helps to clarify the scope of the solution (as shown in Fig. 1). Furthermore, some of the actors mentioned earlier will interact with the system, and provide enough support to allow the next stage of the design process to begin [46]. Some of these needs are those of different users, multiple devices and environmental changes [48]. Thus, the developers should not just consider average needs, but also their diversity.

The graph plotted in Fig. 4 consists of characters that are framed into layers, called stakeholders in the solution of the system, and represent an artifact of Organizational Semiotics [40]. The layers listed take into account the community and audience, for example ANATEL (Brazilian National Telecommunications Agency), ABNT (Brazilian Association of Technical Standards) and SBC (Brazilian Computer Society). They also consider the market, partners and competitors, as is the case with the suppliers of mobile devices and software that are responsible for the research team, programmers and designers.

Neris and Baranauskas [2, 47, 48] have developed a technique based on Collaborative Analysis of Requirements and Design (CARD) [45]. In undertaking this research, three different types of cards were defined (for users, equipment and the environment), as recommended by [48]. Figure 5 illustrates an example of "cardboard" for a group of users. These cards describe features related to intentions to use (pragmatic impact), the domain terms (semantic differences) and the social impact. The use of these cards gives rise to the different intentions to use and knowledge-based systems domain [46]. The examples shown in Fig. 5 reflect the characteristics of elderly smartphone users and the features of the devices. The factors listed include defects of vision as a possible physical characteristic, usability as an objective and the degree of satisfaction of the user with regard to the mobile device.

Additionally, the card describes general specifications, since the most essential feature is simplicity. In the field of emotional issues, for example, some of the following factors can be highlighted: impatience among the users when they use the smartphone; a lack of curiosity or interest in handling this device; awareness that it is something new; and a fear that they might break it. The card for the device considers the features related to input and output information, for example the keyboard and screen, as well as physical features, such as the screen size, processing power, memory and amount of data. The card for the environment is characterized by issues regarding network connection communication, cell phone signal and brightness. The cards can be filled in by one person, or by the designers, during the participatory practice [47]. Furthermore, additional fields can be included in the card in accordance with the needs of the project. The cards can also be grouped to form a context table.

However, the final stage of the first pillar details the context of use and its special features, through noting the interaction requirements with the interface [46]. These requirements are formalized with the help of Ladder Semiotics [61]. Thus, on the basis of the experiments with the elderly and the information obtained from the cards filled in by the users, the equipment and environment can be established as the requirements and layers of interaction distributed through Ladder Semiotics.

The ladder allows semiotic information (signs) to be viewed from different perspectives [41, 61], starting from the physical world, and moving on to empirical, syntactic, semantic and pragmatic areas, and finally the social layer.

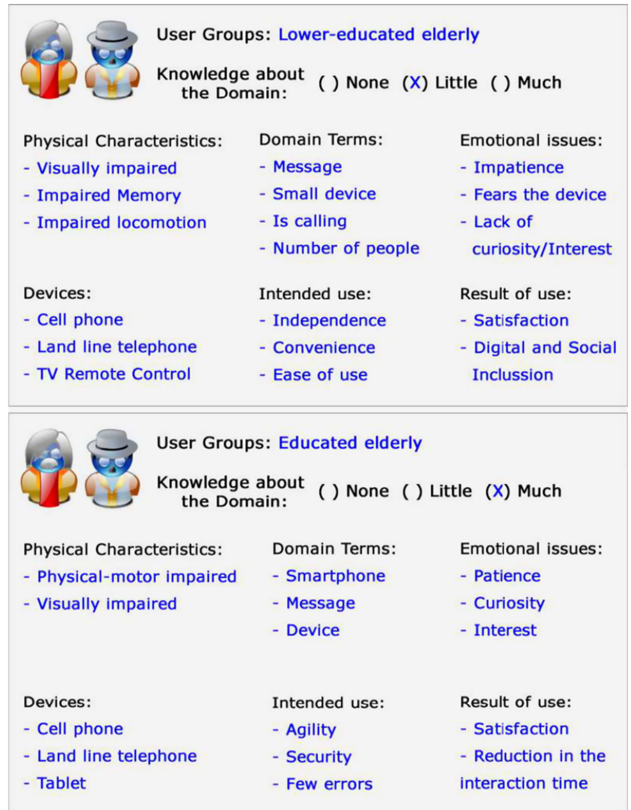
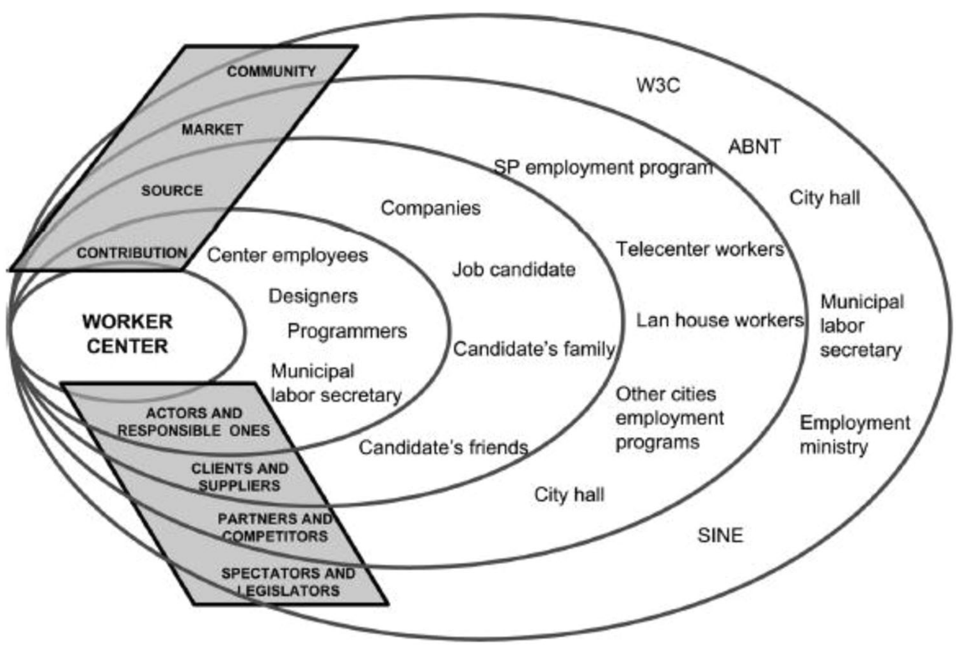


Fig. 5 Cards for the characterization of the user groups

The three layers at the bottom comprise the IT platform, which supports a system where most people's attention is centered on the system design. The different layers are the following:

Fig. 4 Stakeholders' chart



- *Physical World* Issues in this layer are related to the hardware that supports the system, including the paths over which information is transmitted and the capacity of the route. That is, this layer relates to all aspects of a material system. For instance, one problem belonging to this layer is that it has a very mobile screen touch for certain situations. This means you only have to use your finger to scroll the phone book and look up a contact, and it can end up by selecting an unwanted contact.
- *Empirical* The empirical factor relates to the coding, where the statistical behavior of the messages can be combined more effectively with the statistical characteristics of the media (signal error rates). The main question of this layer arises from the encoding since it allows an efficient use of hardware resources. For example, in this study, these are issues of memory and network traffic smartphone.
- *Syntactic* The formal structure of signs is related to the syntactic layer. For example, an alternative path in the smartphone is needed to send an SMS (Short Messages Service) or to handle the size of the interaction elements.

The three layers on top of the ladder form the functions of human information, which are linked to features of human/social organization:

- *Semantic* This domain establishes signals with actions that can be derived from them, or the meanings that are suggested by the elements of a system.
- *Pragmatic* This layer is associated with intention; understanding the context of users is essential in this area, since this allows them to predict how they intend to use the system. In the case of the elderly, issues of independence and ease of use should be given priority. From the observations, it is clear that the functionality of connecting to a given number (such as a favorite program) and saving a contact should be simplified.
- *Social world* The top layer of the Semiotic Ladder consists of standards that govern an organization and its environment. This includes not only legal or cultural standards and ethical considerations, but also the impact the system has on society. In this study, the requirements are related to the user satisfaction of elderly people and issues of digital and social inclusion.

Figure 6 illustrates a ladder which, in the context of the interaction of users, has been partially filled with older applications for mobile devices. The following points were mentioned: the requirements for adapting to the screen size of the smart phone (the physical layer), offering alternatives to increase the text for better visualization (empirical), allowing a more accessible navigation structure (syntax), offering a simple and significant call to contacts (semantics), reducing anxiety and increasing curiosity about the device (pragmatic) and providing social integration (social world) [25].

4.2 Pillar II (second phase): definition of functionalities

From the techniques and approaches that have been examined so far, it is possible to have a consistent view of the field and be aware of how it has originated from a particular social context. On this basis, the second pillar of PLuRaL enables designers to define the features of the application and understand how they will behave and be adaptable through the description of use cases and ontologies for the domain and by adopting a systematic approach [46]. However, in this study, the interfaces were designed to tailor functionalities that are already implemented in mobile devices. Thus, the related functionality to save/edit contacts in the smartphone and make calls was set to provide tailored features on their interfaces.

Again, as this stage defines the functional behavior of the target application, the second pillar for this particular software is relatively simple (i.e., to create a new contact and following this, to make a phone call to the contact that has just been saved). The reason for doing this is to show each PLuRaL pillar in a straightforward way and thus help readers understand it promptly.

4.3 Pillar III (third phase): definition of tailorable behavior

Since the features have already been defined, the third pillar of PLuRaL is applied to determine the adjustable behavior, which includes the sequence of actions and alternative flows. The final stage of the framework seeks to examine design proposals that meet the requirements of the Semiotic Ladder, by defining a set of characteristics that is applicable to users, devices and environments, as well as the system behavior. As a result, a system that has a specific functionality and a particular representation may have a single functionality which is represented by different user interfaces.

The last stage in the PLuRaL framework includes outlining user interfaces, through a participatory practice. According to Wulf et al. [68], simple designs are insufficient to represent the diverse elements of a measuring system; hence a more formal approach needs to be adopted.

Accordingly, Fig. 7a represents the mock-up of a flexible interface targeted at the elderly with little schooling, where it can be observed that the scroll bar and a larger keyboard have been excluded. Even at this stage, it is

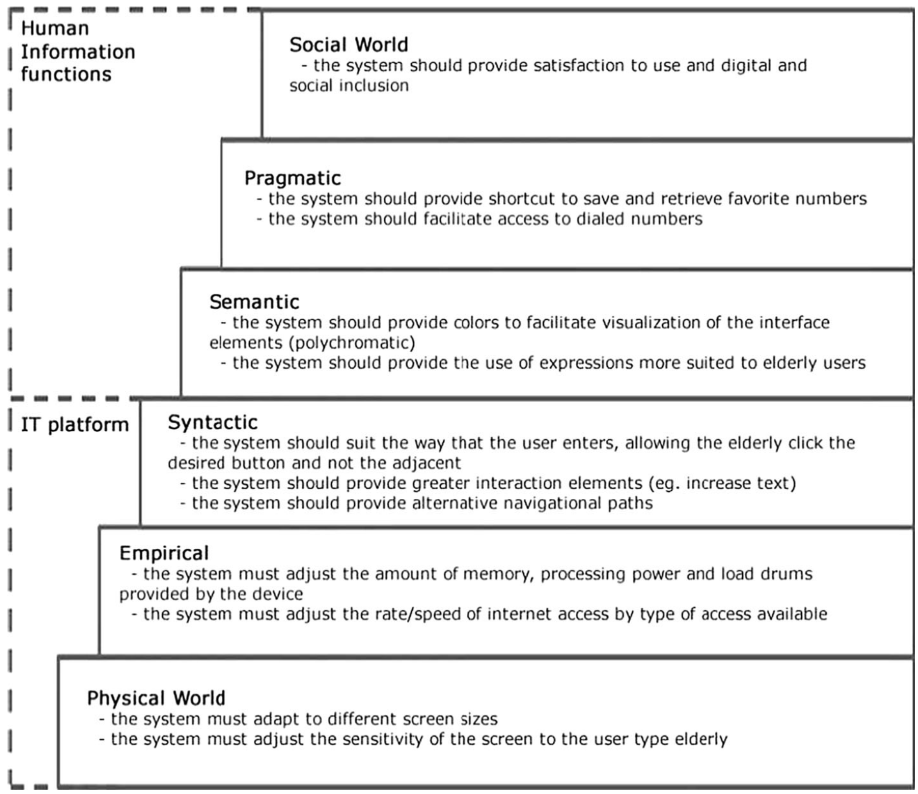


Fig. 6 Semiotics Ladder with the requirements for the adjustable interface

possible to set a mock-up that takes account of educated elderly users (as shown in Fig. 7b) where there was a need to ensure consistency and standardize the procedure so that the interface elements were comparable with those of other similar systems.

After establishing the adjustable behavior, one is in a position to characterize the activities of the elderly and find alternative ways of interacting with smartphones. This means that in this third pillar, a wide range of settings can be modeled (as described in Table 6), where situations are described by the designers as "simple." Whenever a user dials a number and types a mistake, the application of this keyboard must be reconfigured to a more appropriate size for this user.

5 Implementation of flexible interfaces with OpenCom

5.1 Overview of the implementation

By using the set of rules that were defined in the previous section, for the design of flexible interfaces for elderly users, it was possible to develop a functional prototype which provides interfaces that can be adapted to the older public during run time. FlexInterface is a framework that assists in implementing flexible interfaces, developed by means of Adaptive Middleware OpenCom [27, 64]. With the aid of this resource, it is possible to have mobile phone interfaces that can be adapted to different older user profiles. In the preset approach, (a) "interfaces" express services that are provided/offered by each component, while (b) "receptacles" describe required services by means of components. Finally, (c) "bindings" denotes connections between two components and can be either created or destroyed while creating the desired runtime adaptive software system.

The prototype was implemented in Java using Android version 2.2, running on Samsung GT-5 Galaxy I5500B. OpenCom is a component-based platform (i.e., based on a software component approach) that allows new components to be loaded whenever required and also enables components to be destroyed when no longer required. This is a crucial feature for FlexInterface as a resource-constrained device such as a smartphone is involved; this kind of device needs to save power, by processing cycles and memory whenever possible. Hence, the needed interface is deployable when required and its instance is destroyed when it is no longer demanded. In this way, it is possible to save smartphone memory and only deploy pluggable component interfaces that are identified as required. In addition, by following this approach the smartphone interface can be adapted to the context in which it is placed.

It should be noted that to achieve the above-mentioned adaptation, the OpenCom middleware approach is

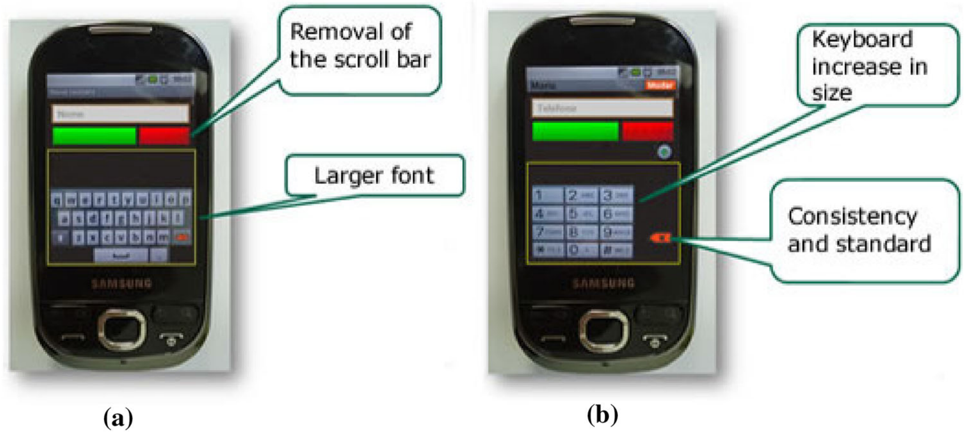


Fig. 7 **a** Mock-up for less-educated elderly people. **b** Mock-up for educated elderly people

Table 6 Examples of standards that represent the behavior of a flexible smartphone that meets the diverse requirements of elderly users

Type of user	Functionality	Representation	Tailorable behavior element and mode
Education level less than 4 years	Search contact	Contact list and index	Remove scrollbar
Memory deficit	Save	Form	Polychromatic
Education level more than 4 years	Buttons	Save and cancel	More significant
Inexperienced in the use of smartphones	Save	Form	Fewer fields to fill
Physical motor deficit	Dial	Key	Greater distance between the keys
Elderly experienced in the use of smartphones	Buttons	Save and cancel	Monochrome
Elderly with vision deficit	Dial	Keyboard	Enlarge keyboard

followed. OpenCom is a component-based platform (i.e., based on a software component approach) that allows new components to be loaded whenever required and also enables components to be destroyed when no longer required. This is a crucial feature for FlexInterface as a resource-constrained device, such as a smartphone, needs to save power for processing cycles and memory, whenever possible.

Figure 6 does not only show examples of adaptation, but also the design requirements for the elderly from different perspectives of the Semiotic Ladder (SL). These requirements were identified at a previous stage (i.e., at design time relying on PLuRaL) and were addressed as follows. The implementation of the FlexInterface has one component to meet the requirements of one level of the SL, i.e., each can use one small component to deal with one requirement, and a normal component for each level of SL. This means that if a new requirement is found at a specific level of the SL, only the FlexInterface component that handles that level needs to be changed.

These requirements were examined at design time relying on PLuRaL for the basic task of saving a contact to the phone and thus calling the contact. A sheet of paper was handed to the users with the name and phone number of a person that they need to save as a contact on the smartphone and then asked them to call to the number given. The default Android contacts manager user interface (UI) provides all the contact information on the same screen (name, organization, phone, groups and so on). It also provides a scrollbar that is hard for an elderly user to identify. However, this is too much information for elderly users and this makes them confused. The following adaptations were made for both elderly groups: only one contact field per screen; when a new screen is loaded, a recorded voice tells the user what he has to do (e.g., you should put the contact name in the textbox); every screen has a button to accept input by voice (i.e., the user could speak instead of typing); there is a back button on every screen that is more visible than the physical button of the smartphone. The keyboard was an adapted version in a normal size, and the size of the keyboard was changed if the user made an error, for example typed the wrong letter instead of the desired letter.

In the case of the group with a low level of education, the UI elements were customized with different colors and fonts, and each button had a different color to help make user interaction easier. Only the basic contact information was needed to register a new contact, though more information could be added at the end of the process if required. In the case of the other group, some UI elements had similar colors and fonts to the Android UI; however, they were adapted to meet the design requirements, and all the contact information was shown in the screen sequence even though the field was optional. Eight components were implemented that are runtime deployable with regard to the target needs/profiles of the elderly users. The elderly user profile is determined by the ElderlyProfileChecker component that is connected to another one called ElderlyFlex. All of this is described in Sect. 5.3. The overall design of the prototype is shown in Fig. 9. Note that the arrows indicate that a given component can be replaced by another (e.g., the LowEducationKeyboard component can be replaced by the DefaultKeyboard component and so forth).

5.2 The FlexInterface approach

This research adopts a generic approach to build adaptive applications for mobile devices. The works [13, 36, 64] show that runtime reconfiguration is a key feature in handling the heterogeneous hardware that is inherent in mobile devices. This means that by defining the design of flexible interfaces so that they met the many interaction requirements of the elderly with mobile phones [9, 26, 27, 58], it was possible to develop a software layer called FlexInterface based on the OpenCom component model [27, 64].

FlexInterface is generic and has a flexible and extensible architecture that is not dependent on language. It is based on a microkernel, where the functions are incremented upon request [36, 64]. In this context, it is worth drawing attention to FlexComp, which is a generic and reflective component of FlexInterface and has two receptacles called FlowScreen and ProfileChecker (as shown in Fig. 8).

The FlowScreen component is responsible for storing the sequence of actions/screens that a given older user profile possesses, so that it can carry out a task in the device. Thus, with FlowScreen it is possible, for example, to determine a sequence of specific screens, for older adults with a low level of education, and to record a contact in the cell phone agenda (for example flow of actions/screens: Record Name > Record Phone > Save Contact). Additionally, the ProfileChecker component receives the users' interaction data and, on the basis of this information, is able to set the most appropriate type of profile and then determine whether it is necessary to reconfigure the FlexInterface components.

5.3 FlexInterface for older users

FlexInterface is a framework supported by the development of adaptive interface designs that allows the application to adapt to the needs of the user during his interaction with it. With regard to the many requirements which emerged in the case study with the elderly and which led to a set of rules being defined for behavior-based adjustable interfaces [25], two different profiles of elderly people were selected: seniors with up to fourth-grade education (low education) and those with education beyond the fourth grade (high education).

Given the range of requirements, FlexInterface was used to provide adaptability to the interfaces. This meant that, as well as a change of actions/screen flow and of the interface elements, changes in the structure and size of the keyboard were also necessary. In view of this, the ElderlyFlex has been created, which is an extension of the FlexComp of the FlexInterface. This extension includes a new receptacle that is able to load the keyboard component and is suitable for the profile that is determined by the ProfileChecker (as shown in Fig. 9).

Thus, the keyboard is represented by three components which have been devised to meet the requirements of elderly users: (1) default keyboard, (2) a system for the elderly with low education and (3) a system for the elderly with high education (DefaultKeyboard, LowEducationKeyboard and HighEducationKeyboard, respectively). Depending on how the user interacts with the application, the ProfilerChecker sets the most suitable profile at runtime and enables the ElderlyFlex to connect to the keyboard component that is most suited to the profile (as shown in Fig. 10).

Data were collected from the user input to determine which keyboard was best suited to each user profile of the elderly. The following information was collected for each keystroke: (1) given character, (2) elapsed time (ms) from previous tap and (3) error (when the user deletes a character). With regard to the FlexInterface architecture, the components that require the screen flow, FlowScreen, were developed. For this particular scenario, it was possible to explore the reconfiguration of the actions/screen flow. In this case, the ProfileChecker defines the interaction profile and analyzes the use of a new layout with a different action flow that can be used for the interface at the appropriate time.

Thus, owing to the change in the user's standard interaction, in the scenario in which the default screens/actions flow component (DefaultFlow) is loaded, the ProfilerChecker can, for example, set the "low education" as the most appropriate default for this older user. As a result, the default flow component will be disconnected and destroyed, freeing up the memory; following this, the screens/actions flow component for lower education

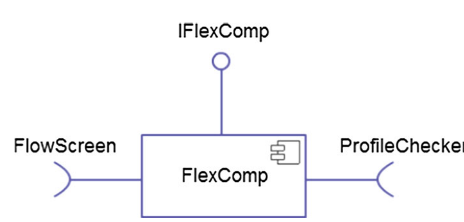


Fig. 8 ElderlyFlex component and its receptacles

(LowEducationFlow) will be created and connected to ElderlyFlex, thus making the application suitable for the new default interaction. It should be noted that when the screens/actions flow reconfiguration is added, the screens of each flow establish the interface layout formatting, the position of the keys, the colors and the voice access, by strictly adhering to the rules defined by [25] and using the PLuRaL framework [47].

6 Evaluating FlexInterface

6.1 Senior citizens and the flexible interaction

The observation of the elderly interacting with the smartphones took place in a CRAS (Social Assistance Reference Center). These users form a part of a group that carries out physical activities intended for seniors (these users are different from the users shown in Table 4). In parallel to these activities, eight people were invited to participate in some interaction tasks with the smartphones, as described below.

First, the users were profiled and divided into (1) users with no formal school education, or never used smartphones, or just used them to answer calls, and (2) users with higher or secondary education who as well as making calls, also send messages, take pictures, edit contacts and play on their smartphones.

A concept test was conducted for this application scenario which allowed the interface to be adapted to two user profiles, and defined by [22]: "The elderly with low education (who had studied up to fourth grade), and the educated elderly (those who had studied beyond the fourth grade)." It was found that the low/no education profile was characterized by a poor experience of using smartphones. The participants worked in pairs and each individual had a smartphone. The user's profiles are described in Table 7. During the test, the pair sat side by side during the smartphone interaction. In addition, these users were shown a paper that had the name and phone number of a person they had to save in the smartphone's phonebook and were then asked to call the number in question.

While the users performed the task with the smartphone, the researchers conducting the case study filled out an observation form with questions (as can be seen in Table 5). The elderly were also told that, if necessary, they could help, or ask for help, from their partner. The pairs were defined by carrying out an analysis of the profiles that took into account age and education. This enabled the users with similar ages and education levels to be grouped together. After completing the task, the authors held a discussion session with the pair and raised issues related to flexibility, the requirements met and the difficulties encountered during the smartphone interaction.

6.2 Performance and overhead

This evaluation measures the performance and overhead incurred by FlexInterface on a Samsung GT-5 Galaxy I5500B smartphone with the SO Android version 2.2. The device has a band quad (850 + 900 + 1800 + 1900 MHz) processor and 184 MB RAM memory, along with 32 GB storage capacity microSD. The aim of this test is to analyze the overall impact when implementing FlexInterface in a

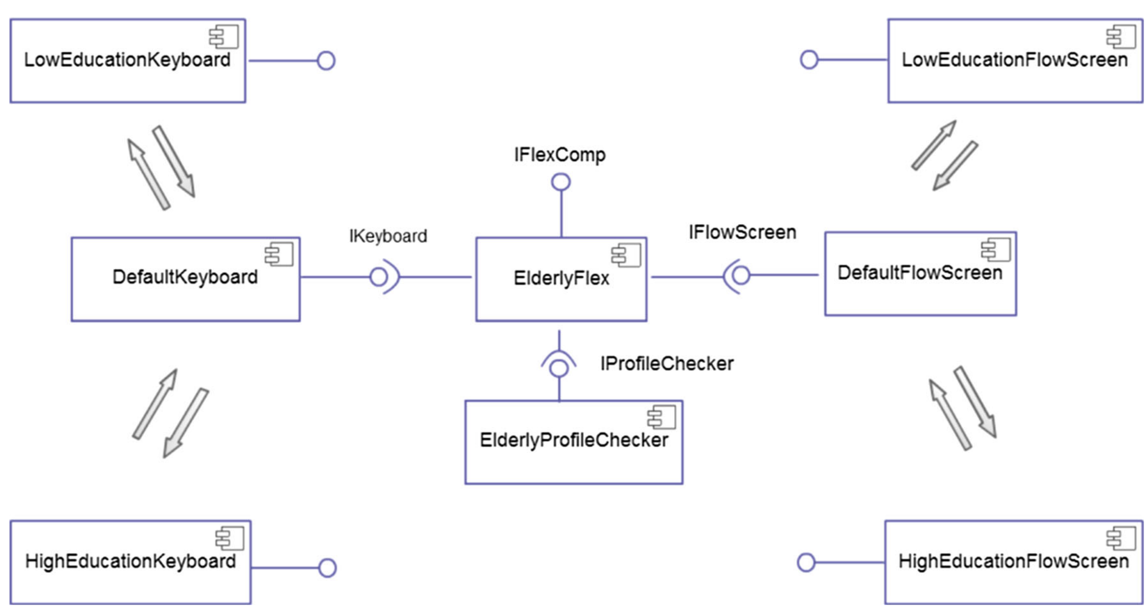


Fig. 9 FlexInterface components along with implemented pluggable components

Fig. 10 Default (at *left*) and adapted keyboard (at *right*)

device with scarce resources. With this in mind, the same measurements, i.e., the overhead measured to load and instantiate FlexInterface components, are computed and compared against those of Java objects.

In the instantiating process, a FlexInterface null component took 452 ms compared to 10 ms to instantiate a Java null object (as can be seen in Table 8). The variations in the measurements can be attributed to the larger file size that is required by the FlexInterface components to store information for the metadata. It can also be attributed to the complex instantiation mechanism that is used by the FlexInterface, which includes the time required for storing information about components, its interfaces and the receptacles in the register.

The register keeps all the information about the components, interfaces and receptacles handled by the FlexInterface kernel. As a result, new instantiations of components, interfaces and receptacles that have been previously instantiated only take a negligible amount of time to instantiate. It was found that when the total load, the instantiation time and registration mechanism of FlexInterface are taken into account, the FlexInterface overload is not very different from that of Java.

Figure 11 shows a comparison between the memory use of FlexInterface components and Java object. The memory use of a null Java object is 39 bytes, whereas in a FlexInterface component without receptacle or interface, it is 52 bytes. Moreover, the memory use was found to be practically equal, even though the component is more complex than a null Java object. In this graph, it can be seen that a receptacle uses approximately three bytes, while an interface uses five bytes. It can thus be inferred that a FlexInterface component with a receptacle or interface does not consume significantly more memory than a null Java object.

This paper developed a FlexInterface to meet the different interaction requirements of elderly users in a flexible approach aligned with Universal Design principles [11]. This is based on the OpenCom components model [64] that supports the development of adaptive interfaces for mobile phones, by enabling the application to suit the needs of elderly users during their period of interaction with the device. Furthermore, the solution was evaluated in an experiment conducted with elderly people. A group of elderly users was observed while they were interacting with cell phones and using FlexInterface, to determine whether the implementation of the adapted behavior of the interfaces (defined in Sect. 5) is suited to their different user requirements.

6.3 An analysis of how the elderly interact with the flexible interface

This section presents a nonparametric test carried out with the aim of determining whether there is an improvement in the interaction of users with FlexInterface; the parameter

Table 7 User's profile

Elderly people Pair ID	Gender	Age	Education level (years of formal study)	Home phone usage	Smartphone usage
P1	F	81	Less than 4 years	Daily	No
	F	84	Less than 4 year	Never	No
P2	F	66	Less than 4 year	Daily	Yes
	F	60	Less than 4 year	Daily	Yes
P3	F	61	More than 4 year	Daily	Yes
	F	60	More than 4 year	Daily	Yes
P4	F	65	Less than 12 years	Daily	Yes
	M	69	Less than 12 years	Seldom	Yes

Table 8 Performance of FlexInterface in Samsung Galaxy 5 GT-I5500B

Operation	FlexInterface	Java object
Loading time (ms)	12	58
Instantiation time (ms)	452	10

that was used was the practice of elderly people interacting with non-flexible smartphone interfaces. A set of standards, defined with the support of the PLuRaL framework, was implemented to obtain a flexible solution; this was employed to evaluate the elderly, with the aim of measuring the interaction time and the satisfaction of these users. While the interaction time (*t*) was being estimated, the users were being filmed and measurements to assess their level of satisfaction were recorded, as well as a number of favorable and unfavorable comments. The results were compared, in a nonparametric test, together with the flexible solutions. The users employed the same devices and then performed the same task with flexible and non-flexible smartphone interfaces. From the sample, 68 % of the users participated in the group that interacted with the flexible interface. The average age of both groups was approximately 69 (standard deviation of about 8 years). The level of education of the elderly in both groups ranged from no education (19 %), post-graduation (10 %), with the majority (45 %) being from the first to fourth grade.

In the statistical analysis, a variable degree of satisfaction was classified in different levels (very low 0–19; low 20–39; good 40–59; very good 60–79; and excellent 80–100). Figure 12 shows the levels of user satisfaction while performing the flexible task (Fig. 12a) and non-flexible task (Fig. 12b). Regardless of whether or not the flexible task was completed, the degree of user satisfaction varied from 67 to 100 %; if the task was non-flexible, the degree of user satisfaction varied from 33 to 67 %.

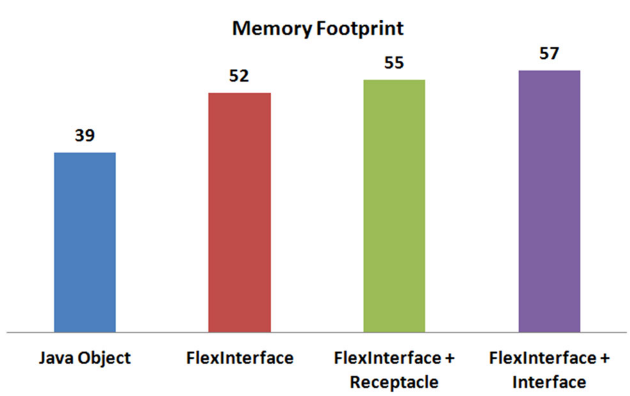


Fig. 11 FlexInterface memory consumption. Comparison between the memory use of FlexInterface components and Java object. The memory use is practically equal, even though the component is more complex than a null Java object

A statistical evaluation was carried out using the Mann–Whitney test to compare the execution times for the flexible and non-flexible tasks [12]. In this study, the sample space is small for a number of reasons, such as the difficulty of finding people with the needed characteristics. Thus, a nonparametric approach was employed. Generally speaking, this methodology is used when the sample space does not have a normal distribution or when there are qualitative variables. This approach is also justified by the fact that the distribution was not identified for the investigated variable (i.e., time needed to execute a task) for this sample size.

The assumption underlying the application of the test is that the observations of the two groups are random and independent of each other and that the measurement scale is at least ordinal. The hypotheses can be expressed as follows: H0: E(X) >= E(Y) and H1: E(X) < E(Y). In other words, the null hypothesis (H0) of the test is that, on average, the results from group 1 taken from the population are at least equal to the results of the group removed from the second population and the alternative hypothesis (H1) is, on average, that the group results taken from one population are lower than the results of the group removed from the second population.

The Mann–Whitney test has been applied in the runtime tasks (flexible and non-flexible). In this case, the hypothesis that is equal, on average, to the behavior of twice the proposed time is based on the assumption that, on average, the behavior of the proposed time is less flexible than the flexible proposal. In this case, the hypothesis is rejected (p value $= 0.001$). That is, the runtime task proposed for flexible tasks is on average less than the time of the proposed non-flexible tasks. The graph in Fig. 13 shows the behavior of this variable in each situation. Note that 50 % of users performed the task in the flexible task in up to 5 min, while the non-flexible task was performed within 10 min. Similarly, the Mann–Whitney test was applied to the variable degree of satisfaction experienced in carrying out the tasks (flexible and non-flexible). In this case, the evaluated hypothesis is that it is equal, on average, to the degrees of satisfaction for both proposed tasks and assumes that the degree of satisfaction of the proposal is less flexible. The hypothesis was rejected (p value < 0.001). That is, the satisfaction obtained from carrying out the task is higher when it is flexible. The graph in Fig. 13b shows the behavior of this variable for both tasks. Note that 50 % of the users showed a satisfaction with flexible tasks between 83 and 100 %, and there is a non-flexible satisfaction between 14 and 29 %.

7 Final remarks

This paper proposed an approach to devise adaptive user interfaces targeted at elderly people. An entire scheme for developing an adaptive smartphone interface for the elderly

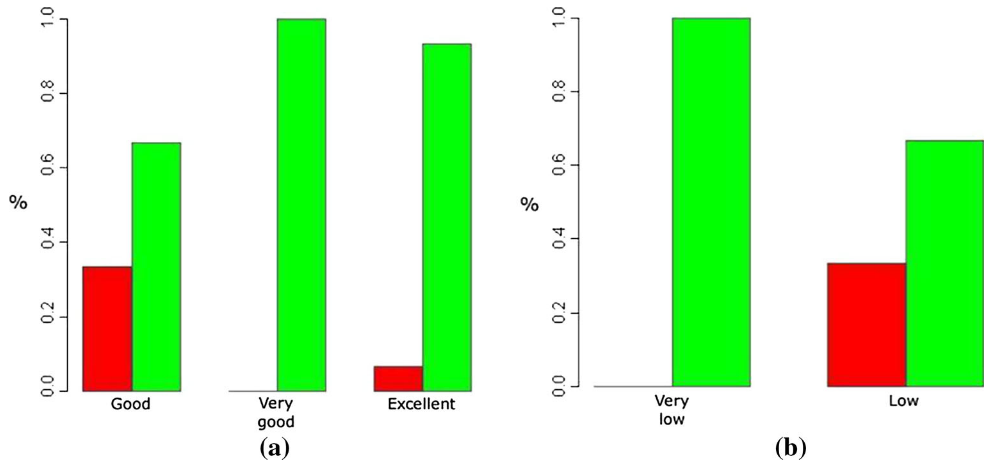


Fig. 12 Degree of satisfaction on completion of second task (*green* = yes, *red* = no). **a** With flexible interaction. **b** Without flexible interaction (color figure online)

has been provided. It should be stressed that the approach proposed takes into account the existing diversity that can be found in this targeted audience. The sample includes people who are not familiar with the technology, and differ considerably with regard to their educational background, experience with ICT and cognitive skills. This kind of diversity is relatively common among elderly people and as observed, it was the outcome of their education and work experience. All of this suggests the need for flexible approaches that can encompass the full extent of the diversity found in this audience.

This paper has discussed the whole procedure of developing flexible smartphone interfaces from the very beginning, i.e., from the initial design of the interfaces. In undertaking this, issues resulting from a real experiment with elderly people interacting with a smartphone (from defining requirements to the design phase) were planned, performed and discussed. The authors propose the use of PLuRaL design, as it is particularly applicable for designing flexible interfaces: the PLuRaL framework sets out guidelines that can be employed by designers for the generation of required specifications and functional descriptions, including the tailorable behavior of the interfaces. With regard to its implementation, the OpenCom middleware approach was adopted, as it enables the construction of runtime reconfigurable component-based systems [62]. The built prototype is called FlexInterface and is based on a microkernel-based approach which is the same as the microkernel-based operating systems. A minimum microkernel for FlexInterface was developed, in which interface functionalities are deployable at runtime whenever required and destroyed when no longer needed. In that respect, the smartphone interfaces are configured and reconfigured according to the targeted elderly user, as well as the application domain and needs. This means having low overhead (e.g., low memory usage) as only requested functionalities are deployed when needed. It should be underlined that this feature is important as smartphones are resource-scarce devices. In addition, with this runtime reconfigurable implementation, one is able to meet the requirements of each elderly user and thus address the problem of diversity mentioned above.

In future work, the authors aim to extend this approach to those with special needs (e.g., people with Parkinson's disease or Down syndrome). For example, there are different degrees of Down syndrome, which means that there is an issue of diversity as well. In view of this, it can be argued that this could be a fertile ground for the proposed flexible approach. This will also help bring about the digital inclusion of people with special needs. In addition, to the plan is to define design rules for flexible interfaces, which target other interaction domains for older adults. The research considers the development of a classifier that can learn from the interaction of past users and can present, automatically, an adequate interface for a new user. This classifier can be based on information obtained during the user interaction, e.g., the time to execute a task, task execution errors, task completion, among other factors, to dynamically adapt the user interface. Feasibility tests of FlexInterface and other devices will be carried out, such as tables used by older adults. Finally, emotional factors involved in a task execution will be considered when defining and implementing the dynamic generation of a user interface.

To conclude, the authors believe that this research study raises the question of the need to seek computing solutions that embrace the diversity of human beings, and thus be able to address the largest possible number of users regardless of their physical, cognitive and emotional

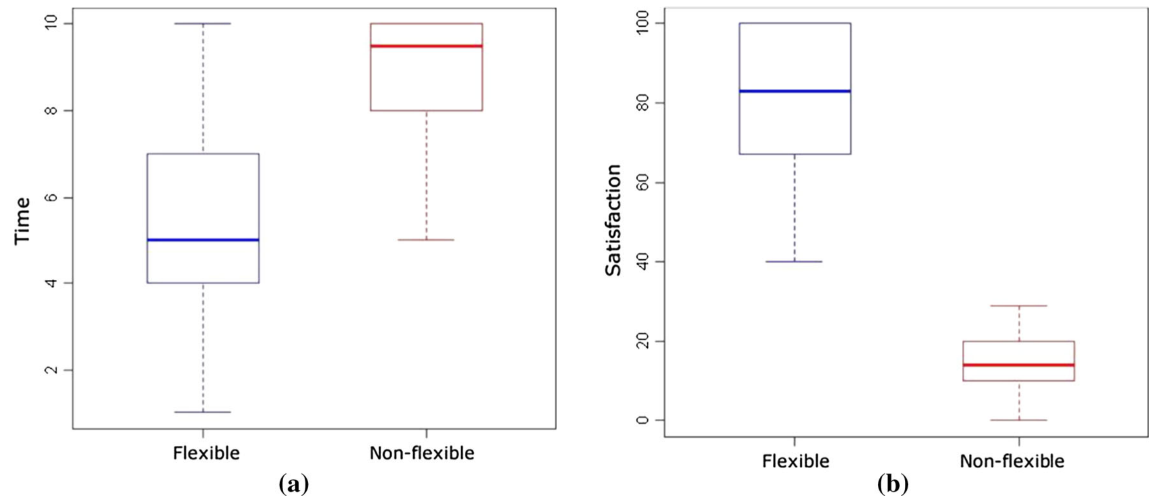


Fig. 13 Boxplot. (**a**) Task execution times. (**b**) Degrees of satisfaction, in each situation

condition. It is hoped that the ideas outlined here support the design of custom interfaces, by recognizing and respecting the fact that diversity can be found in any user group.

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