Journal of Autonomous Intelligence (2024) Volume 7 Issue 1
doi: 10.32629/jai.v7i1.762

ORIGINAL RESEARCH ARTICLE

Enhancing quality of life: Human-centered design of mobile and smartwatch applications for assisted ambient living

Gonçalo Augusto[1], Rui Duarte[1,2,*], Carlos Cunha[1,2]

[1] *Polytechnic Institute of Viseu, 3640-218 Viseu, Portugal*

[2] *CISeD—Research Center in Digital Services, 3640-218 Viseu, Portugal*

*** Corresponding author:** Rui Duarte, pduarte@estgv.ipv.pt

ABSTRACT

Background: Assisted ambient living interfaces are technologies designed to improve the quality of life for people who require assistance with daily activities. They are crucial for individuals to maintain their independence for as long as possible. To this end, these interfaces have to be user-friendly, intuitive, and accessible, even for those who are not tech-savvy. Research in recent years indicates that people find it uncomfortable to wear invasive or large intrusive devices to monitor health status, and poor user interface design implies a lack of user engagement. **Methods:** This paper presents the design and implementation of non-intrusive mobile and smartwatch applications for detecting older adults when executing their routines. The solution uses an intuitive mobile application to set up beacons and incorporates biometric data acquired from the smartwatch to measure bio-signals correlated to the user's location. User testing and interface evaluation are carried out using the User Experience Questionnaire (UEQ). **Results:** Six older adults participated in the evaluation of the interfaces. Results show that users found the interaction to be excellent in all the parameters of the UEQ in the evaluation of the mobile interface. For the smartwatch application, results vary from above average to excellent. **Conclusions:** The applications are intuitive and easy to use, and data obtained from integrating systems is essential to link information and provide feedback to the user.

Keywords: mobile application; smartwatch application; beacon technology; user experience; human-computer interaction

ARTICLE INFO

Received: 21 June 2023
Accepted: 31 July 2023
Available online: 25 October 2023

1. Introduction

Now more than ever, the world continues to experience unprecedented significant changes driven by rising average life expectancy and declining quality of life at older ages. People living longer means that the number of older people is increasing globally. The living conditions of older people are an important indicator of their well-being. It should not be forgotten that these are related to culture and the country in which each person lives. The scenario where older people live alone or in institutions raises concerns about their lifestyle. They have more overall mortality risks than those living with their partner or family members.

Older adults must be able to perform Activities of Daily Living (ADL) without assistance to live independently. ADL represents the elements that make up each person's routine (e.g., eating, bathing, and mobility)[1]. The spatiotemporal distribution of ADL models has a behavior pattern, which can then identify behavioral anomalies if something occurs differently. People's families and friends are interested in these anomalies because they express alerts to some conditions that may require their intervention. In this paper, we add a knowledge layer based on design principles that allow older adults and their family members to autonomously install these systems at home without the associated technological burden.

This work presents the design and implementation of a mobile solution to monitor daily living activities, using smartwatches to make it non-intrusive for older adults. Smartwatches can transmit data using communication interfaces (e.g., BLE or Wi-Fi). The data extracted from BLE signals are sent by beacon devices and collected with smartwatches. These BLE beacon devices will be in every room of the person's home. Depending on each compartment's area, one or more devices will be placed in the ceiling. Each room is correctly identified by the BLE beacon(s) installed to generate as much as possible a uniform signal. The data stored in the person's smartwatch is sent to an API for data collection and processing. Therefore, this work's main objective is to develop a user-friendly mobile and smartwatch application that implements a simple and easy solution to configure a pair beacon-smartwatch based on design rules for older adults.

The remainder of this paper is organized as follows. Section 2 presents a review of interaction design, AAL systems, and applications. Section 3 presents a view of the high-level architecture that supports the ideation process and the application features implemented in Section 4. Section 5 presents the results obtained. Finally, Section 6 presents the major conclusions and hints of future work.

2. Literature review

This section reviews the state of the art in fundamental contexts related to the work presented in this paper: interaction design, AAL and representative applications available in the literature or in the market.

Interaction design relates to how people interact with technology by creating user experiences[2]. These experiences must be understood by designers, developers, and creatives so that the focus of the design of interfaces is the user and not the system. To achieve a correct interface design, three contexts have to be taken into account: the User-Centered Design (UCD), User Experience (UX), and User Interfaces (UI). UCD is an interactive design process focused on users' needs during the design process. It consists of several stages: understanding the context of use, specifying user requirements, designing solutions, and evaluating against requirements[3,4]. This process can involve both users and experts at different stages of the process that are not mutually exclusive in the design and evaluation. UCD offers several methods to involve the user in the design, such as questionnaires, interviews, observation, and testing, among others. UX relates to the perceptions of users regarding a product. They can be diverse, and the goal of the measurement of UX relates to usability components and the emotional impact on the user. A positive impact allows the user to accept the interface and is tolerant to faults, while a negative impact determines the interface not to be used. The interaction of users with applications occurs through the UI. It includes all the components that allow users to carry out tasks that cover the user requirements in the context of use. Moreover, to link the interface to the general tendency to model and learn by analogy, metaphors created with conceptual models are essential since they enable users to draw on their existing knowledge to act on a non-familiar domain[5].

The works on monitoring ADL of older adults focus mainly on long-term behavioral analysis[6] in the contexts of daily activities[7–12], abnormal behaviors[13–19], cognitive impairment[20–23], falls[24–28], indoor person positioning[29–31], and sleep quality[32]. Techniques can be broadly divided into video monitoring systems[33], Wi-Fi fingerprinting-based technologies[34], and on BLE fingerprinting-based technologies[35]. Research in recent years indicates that people find it uncomfortable to wear invasive or large intrusive devices to monitor health status[36]. Several AAL reviews have been presented to the community[37,38] and stated that poor UI design implies a lack of user engagement. Therefore, interfaces that can adapt to users[39] should be supported with UI design frameworks in order to reach the goal of independent living.

Current applications in the context of AAL can be categorized in three categories: Daily Activities and Social Connectedness (DASC), Safety Enhancement (SA) and Health Monitoring (HM)[40]. This paper falls into the scope of DASC, where many projects have been developed worldwide and are briefly described in this section. Assisted Cognition Environment (ACE)[41] uses artificial intelligence to support the daily life of older adults by sensing the surrounding and the person's location to determine patterns of potential disorders. The AWARE smart home project[42] aims to establish communication between a patient and families by implementing RFID sensors and vision technologies to identify activities. CASAS[43] uses machine learning techniques to identify behavioral patterns of older adults using motion sensors. This was later improved[44] by introducing monitoring signals to describe the flow of the activities. Similarly, the I-Living project[45] focused on the communications between wireless sensors and a user interface to enhance the independence of older adults. In the scope of integrating smartphones and smartwatches, CAALYX[46] allows the extraction of more information from older adults in the context of a home monitoring system. SOPRANO[47] combines ontology-based techniques and a service-oriented architecture that separates system aspects (sensors and actuators) from context information and system behavior. SAAPHO[48] allows older adults to maintain their independence through a mobile interface oriented toward active aging, healthcare and participation.

3. Materials and methods

This section presents the process of integrating the design of two applications in actual contexts of home setup. The mobile application for installing BLE beacon technology and the smartwatch configuration for beacon detection are presented. It presents a high-level architecture description and a detailed view of the components that make this system self-implemented, thus reducing the need for technological knowledge.

3.1. Design-based approach

Section 2 mentions that the UCD focuses on user needs during the design process. When referring to older adults, user satisfaction must meet one major requirement. In this paper, satisfaction is achieved by approaching the problem in two separate (but correlated) contexts: the first focuses on the identification of requirements, and the second, on the design of the application, composed of graphical interface design and evaluation of the design to meet the requirements.

In the first stage, meetings with the participants were arranged to identify the major requirements, which are as follows:

- Intuitive application and easy to use.
- The system should be as autonomous as possible so that older adults are not pressured to use it.
- The system provides information about their health status.
- Report changes to previous patterns.
- Know the status of the equipment so they feel that everything is working well.

The second context relates to the design of the system and its evaluation. To this end, two approaches are considered: the cognitive walkthrough[49] and the User Experience Questionnaire (UEQ)[50]. First, the user receives a goal, interacts with the interface and provides feedback. Second, the UEQ combines attractiveness, perspicuity, dependability, efficiency, and stimulation in a set of 26 opposing adjective pairs. Moreover, the UEQ avoids extensive tests on the interface that are time-consuming and costly[51].

3.2. Participants and tasks

A total of six older adults were recruited with the following inclusion criteria: (1) do not have much proficiency in the use of mobile and smartwatch applications; (2) live alone or with their spouse. Four were men, and two were women, with a mean age of 72.3 (σ = 3.2).

They were informed on the most critical aspects of the interface: the use of beacon devices (which were unfamiliar to them) to define locations in the house, the mobile application to configure beacons, and the smartwatch application to set up each user in the house. Since beacon technology was not known to users, it was explained how a beacon could represent a location in a home. They were asked to participate in the tests in two stages. First, they were asked to provide information on icon recognition to determine if the icons are well understood in the mobile application. Next, they were asked to execute tasks in the interface that are presented in **Table 1**.

Table 1. Task description.

No.	Task
1	To setup a beacon, find the textbox in the mobile application to insert the smartwatch code to pair both devices.
2	Find the code in the smartwatch to be inserted in the mobile application.
3	Go to the mobile application to start to configure locations of beacons.
4	Insert the code from the smartwatch in the mobile application.
5	Select a beacon that is not yet configured.
6	Add a beacon to a room.
7	Configure all the remaining beacons.
8	Check if the house is configured.
9	Check yout average heartbeat.
10	See your sleep quality.
11	Check the battery charge of the beacon in the kitchen.

No help was provided to the participants when difficulties were encountered. After completing the tasks, they were asked to fill out the UEQ.

3.3. High-level architecture

The high-level architecture description in **Figure 1** provides a general view of integrating separate components resulting in the interaction interface. From the context scenario of installing physical components in a house and creating an immersive system, it is conceptually designed in two components: first, a mobile application allows the setup of the physical system. It maps the representation of the beacons in the application. Next, it is required to associate the user with the beacons. To this end, a smartwatch app is designed.

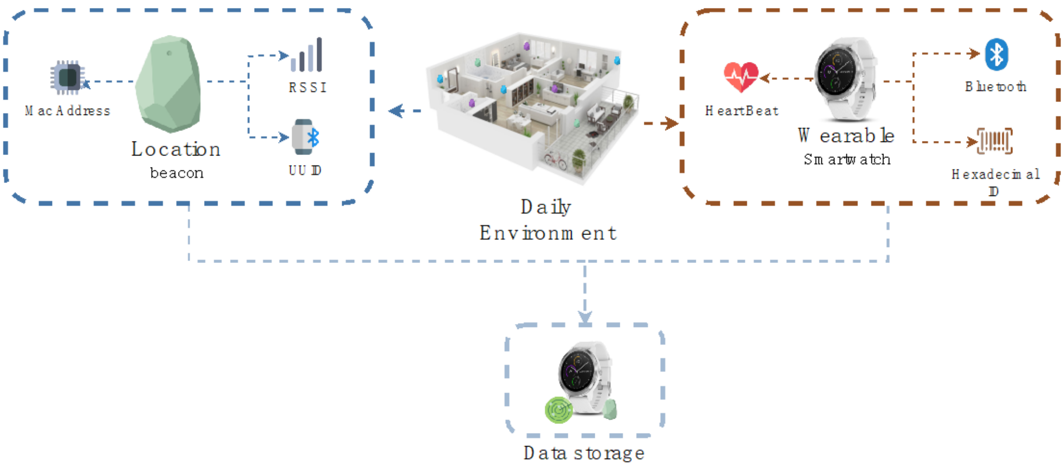

Figure 1. High level view of the proposed architecture.

In each of the systems (mobile and smartwatch), it is possible to identify different features related to a final goal: integrating components for data storage. Data gathering comprises acquiring the beacon's location through the mobile app and identifying the user through the smartwatch widget. This later allows for gathering the most critical biometric data to measure the user's vital signs. This stage generates data stored in a database.

Next, this data is processed to generate information related to patterns of use (which is not in the scope of this paper).

The solution presented in this paper divides into two groups. The first corresponds to the installation and configuration of the devices, where the mobile application is used to associate the beacons with the person. The second corresponds to the collection of periodic data by the smartwatch regarding its passage through each compartment and the Beats Per Minute (BPM). In turn, it sends these to an API responsible for storing the data in the MongoDB[52] database.

A beacon emits a series of information that another smart device can receive and interpret. It is through these outputs emitted by the beacon that the solution will be based, after carrying out the necessary calculations, on which beacon is closest to the user. Thus, the RSSI and TX are critical data for calculating the user's proximity to the beacon. RSSI provides the signal strength varying from −50 to −100, and TX represents the transmitting power, which typically goes from −40 dBm to 4 dBm. The greater the transmitting power, the greater its range is. These considerations influence how the beacons will be installed and mounted in each compartment since the less interference in the signal, the better. Therefore, a beacon is placed in the center of the ceiling in each room (or more, due to the coverage area) since this is the best way to receive each beacon's signal without interference with obstacles or walls. In **Figure 2**, it is possible to visualize the beacon's location in each division.

Figure 2. Example of placing BLE beacons in each room of a house.

To make this solution usable, scalable, and with the potential to grow even further, it is essential to build a sufficiently autonomous system, as it needs little human intervention. In this sense, the only human intervention that this solution proposes is assembling and configuring the devices inside each user's home.

The UCD is based on using of metaphors for the general system and the association of beacons with smartwatches. First, the metaphor of the apartment/house is used for intuitive interactions with the setup of the system[53].

4. Mobile and smartwatch application features

The proposed system's primary goal is to provide a method for the correct setup of BLE beacons and data gathering from the user to create an integrated system of non-intrusive interaction.

4.1. Mobile application

Many mobile applications are available in the market, mainly focused on health monitoring and assistive living. However, most of them are not adapted to support older adults' needs and abilities[54]. The primary objective of this study is to design a smart home mobile application for older adults, considering that several guidelines are taken into consideration[55]. This section focuses on the design and implementation of the mobile application, developed for Android devices using the IDE Android Studio[56], using the Kotlin Programming language[57]. The design of the mobile application, was based on the Material Design[58] guideline system to create components, with support with Figma[59].

4.1.1. Icons

Older adults tend to have difficulties in the identification of new symbolization related to the digital era, and the evolution of technology[55]. The focus was to use simple images representing good metaphors of real contexts related to the older persons' long-term memory. This allows the recognition of tasks instead of remembering a process. Moreover, to reduce the perceived burden, the reuse of elements was considered, allowing the creation of an interface with fewer icons. As a consequence, the correct interpretation of the icons increases. Six older adults were asked to provide information about their perception of icons related to the context of the project, as shown in **Table 2**.

Table 2. User perception of the icons used in the mobile application.

Intention		**Interpretation**					
		User 1	**User 2**	**User 3**	**User 4**	**User 5**	**User 6**
1	beacons define places at home	location of the beacon	beacon	beacon	location of the beacon	location of the beacon	beacon
2	user smartwatch	watch	watch	watch	watch	watch	watch
3	search	find	find	search	search	search	find
4	attention	attention	attention	attention	attention	attention	attention
5	UUID smartwatch number	connect smartwatch	connect smartwatch	connect smartwatch	connect smartwatch	connect smartwatch	connect smartwatch
6	MAC address of beacon	chip	computer chip	computer chip	-	chip	chip
7	accept	ok	check	check	ok	accept	ok
8	RSSI beacon signal	signal	signal	signal	Wi-Fi	signal	signal
9	smartwatch connected with beacon	all connected	connection ok	connected	connected	connected	connected
10	the smartwatch was not found	smartwatch not ok	something wrong with smartwatch	problems with smartwatch	error in smartwatch	smartwatch error	problems with smartwatch
11	search did not produce results	search error	problems in search	search error	no results in search	error in search	search error
12	smartwatch connected	smartwatch connected	smartwatch connected	smartwatch connected	smartwatch connected	smartwatch connected	smartwatch connected

Results show that most icons are understood as they are intended to be. However, some aspects have to be taken into account. First, since beacon technology is unfamiliar to the user, their correct perception of the beacon icon is due to the previous explanation of its representation (one or more beacons are associated with a room in a house and represent that space). Secondly, as expected, the UUID smartwatch number and the MAC address of the beacon were challenging to understand. They are hardware-related icons, and their representation is not precise. To improve the perception, a label is added to the visual representation of the beacon, and a realistic location view is added to the element in the interface. After several tests with other icons, these were the ones that were more related to the representation of the component. All the other icons were well understood by users, with variations in perception, but in the same mental context.

4.1.2. Ideation process

The mobile application is designed to be interpreted as a step-by-step process. This allows older adults to focus on each stage without creating an over-burn in the perception of the complete system, thus minimizing efforts on working memory demand[60,61].

Following the guidelines for the design of applications for older adults[55], several aspects were taken into account and are depicted in **Table 3**. For each guideline, the approach taken in the UI design is presented.

Table 3. Guidelines used and interface design approach.

No.	Guideline	Interface approach
G1	Information or control must be consistent and should be in the same position on every page.	The application repeats patterns of design whenever possible. The reuse of elements is applied.
G2	Screen should have clean and white spaces to keep user's attention.	Adequate spacing between elements is considered with focus on elements.
G3	Important information must be paced in the center of the screen to be immediately visible.	In each step, the focus of the task is provided in the center of the screen.
G4	Avoid scrolling. Long pages must be avoided; if necessary, split into multiple pages.	The application is designed on one page, without need for scrolling.
G5	Hit targets must be big enough for the user.	The size of the elements is adequate for the use of older adults. Fitts Law is applied and visual markers are used throughout the interface.
G6	Place spaces between the targets to be clear and easy to find.	Interaction targets are apart from the remaining elements and are easy to identify (using contrast).
G7	Minimal and clear visual design.	The UI design is focused on the recognition of the task. Irrelevant information is not designed.
G8	Interaction simple and easy to use.	Reduced number of interactions to complete the setup of the beacon.
G9	Create contrast in colors and avoid using too many different and spark colors.	Black and off-white colors are used.
G10	Use a simple one-finger gesture on mobile interfaces (tap and swipe).	95% of tasks use tap and 5% use swipe.
G11	Reduce keyboard interaction.	Use of predefined options placed in lists or in combobox. Only a smartwatch code has to be introduced.
G12	Provide consistent elements and few possible choices.	Reduced amount of icons to represent actions and reuse of elements whenever possible.
G13	Allow users to focus attention in one task at a time.	A step-by-step interface is designed. User focuses only in each part of the interaction.
G14	Allow users to recover from errors.	Context information is provided when something goes wrong.

From the design approach for the application, key elements to consider are the use of contrast, the size of components, and the focus on sub-objectives to achieve a goal. Regarding the last, the application was designed in a step-by-step process: the first consists in searching for nearby beacons and pairing the smartwatch with the mobile application, as shown in **Figure 3**. This results in step two, related to the visualization of all the beacons detected. The next step consists in setting up each beacon in the place of the house where they are located. When all the beacons are set up, the configuration of the system finishes.

At stage 1, the visual representation of elements used in the interface is most important since it will allow the user to recognize design patterns and create in-app associations. **Figure 3** presents the welcome screen, the context of the task (setup smartwatch and beacon scan), and associated error messages focusing on the problem's solution. Some of the guidelines followed are presented. However, all of the guidelines are being implemented.

The application initiates the pairing between the customer's smartwatch and the BLE beacons in each room to assemble and configure the devices. According to the documentation in MongoDB about ObjectId, there are two ways to generate a new ObjectId. The first one is with no argument, which causes the system to create a random but unique one. The second one has one argument and can be given an integer value or pass a unique, twenty-four-character hexadecimal. Interestingly, each smartwatch contains a unique alphanumeric device identifier with a length greater than twenty-four digits, as shown in **Figure 4**).

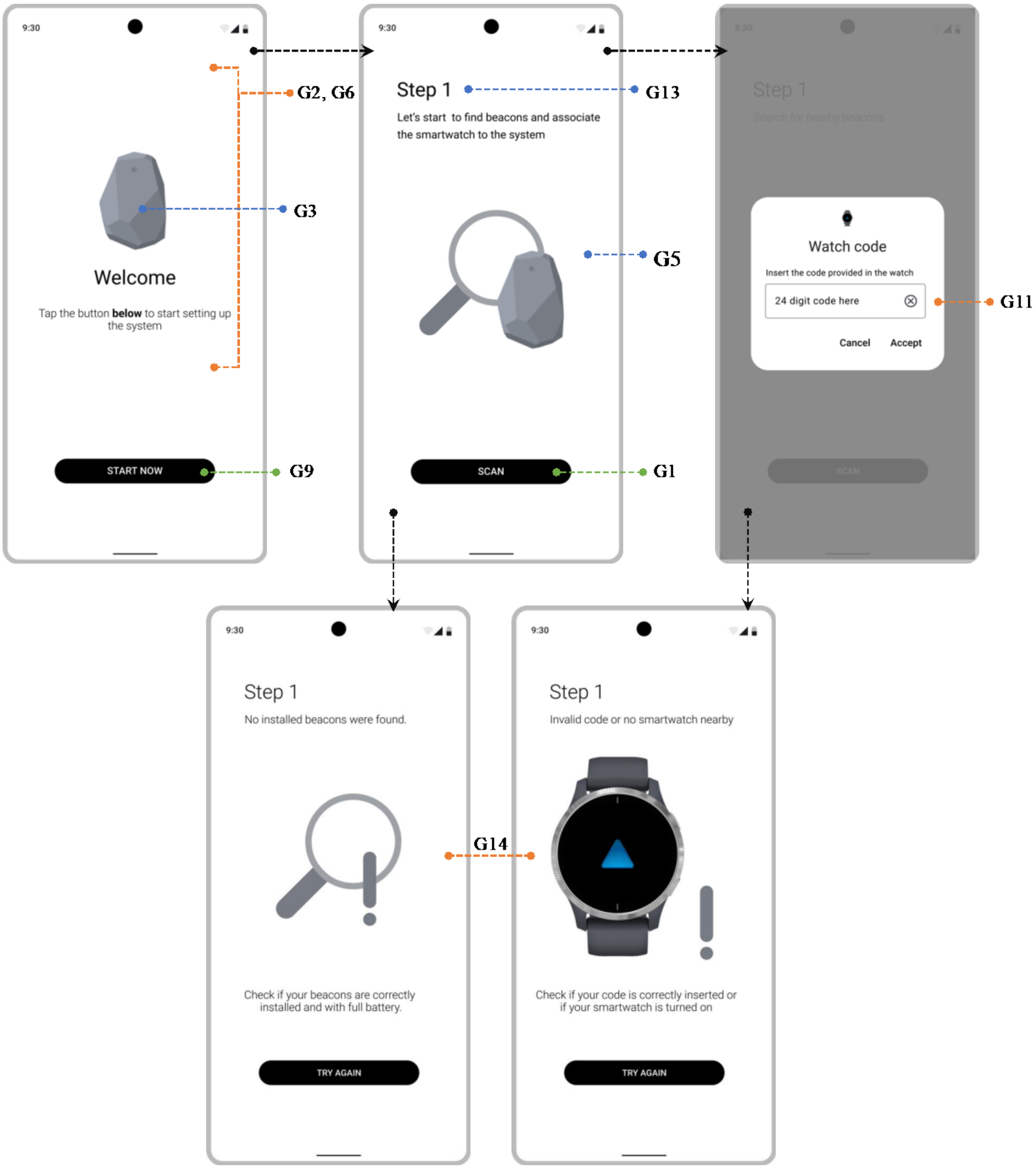

Figure 3. Interface design and application of guidelines.

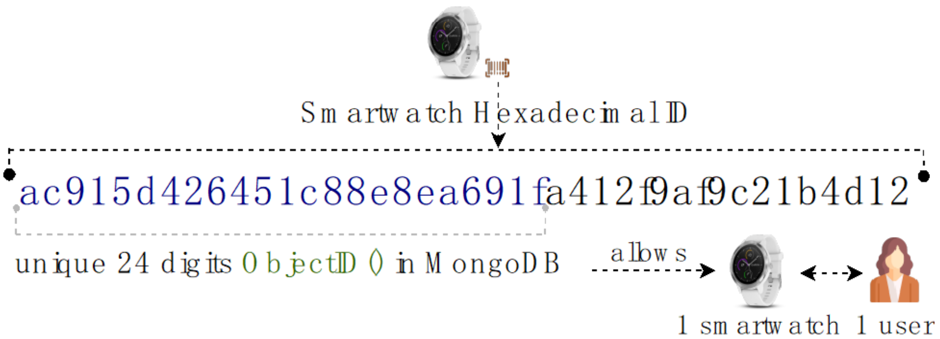

Figure 4. Extraction of the unique alphanumeric device identificer by pairing the smartwatch and the user.

For implementation purposes, twenty-four digits of this identifier can create the ObjectId in the database. With it, the association between the person and the beacons is created and defines a unique identifier that relates the smartwatch to the user.

When the user starts the application, it checks whether the mobile device has hardware capabilities to scan nearby BLE beacon devices. If not, an error message informs that the configuration cannot start because the device does not meet the minimum requirements. If hardware capabilities are found, the user is asked to enter the code visible in the smartwatch widget. At this point, this code must have already been registered in the database by the smartwatch. A pre-communication strategy with the API was developed to automate this verification process so that it does not spend too many resources on the API side. This way, the application is prepared to check if the information that the user has entered meets specific requirements. After these internal checks, the application sends a GET request to the API with the identifier and some request properties, such as verification token, origin, device type, geographic zone, and time zone. If the API responds that it found this code in the database, it sends the application a positive response with code 200 and goes to the next screen. If something goes wrong, it sends a negative response with a code in the order of 400, showing a message that an error occurred.

In stages 2 and 3, the beacons are set up. A listing of all nearby beacon devices is displayed on the second screen of **Figure 5**. In the scan process within the application, a timeout of 10 min was defined so that the mobile device stopped scanning after 10 min. The information of each beacon found is stored in a list with its unique identifier, MAC address, and RSSI. To speed up the process, the application updates the RSSI value shown to the user when an RSSI value different from the previous one is received when the beacon is already saved. It creates a visual effect so that the user also understands the change in the beacon. This functionality was designed to help, even more, the person responsible for the configuration and installation to realize which are the beacons, in real-time, that are more or less close to his mobile device.

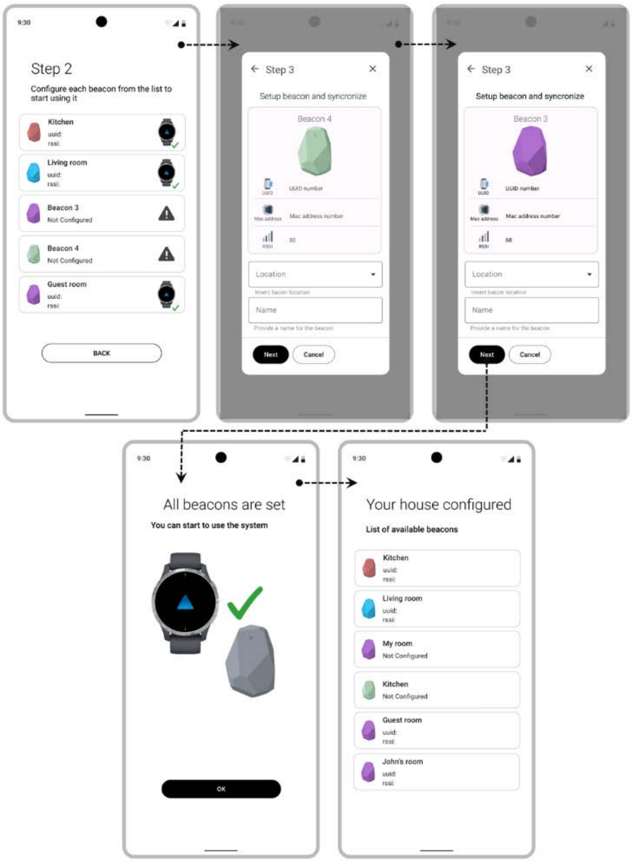

Figure 5. Stage 2 and 3 of interaction. Beacon list and location setup.

Figure 6. Unique hexadecimal identifier extraction.

4.2. Smartwatch application

This section describes the creation of the intuitive smartwatch application to measure the patient's heartbeat and be the device responsible for collecting the BLE signals from the beacons in each compartment and then sending them to the API to store for another system to handle them.

4.2.1. Ideation process

The design of smartwatch applications is a new trend associated with the ability they provide to measure vital signs, which is of significant interest to older adults. The guidelines for the design of Garmin devices are provided in the Connect IQ SDK development site. However, for older adults, and to the best of our knowledge, there are guidelines made available in the literature for smartwatch applications. Considering the size restrictions known on the screen of the typical smartwatch devices, we tried, as much as possible, to apply the general guidelines presented in the work of Johnson and Finn[55]. To this end, the smartwatch application was designed to reduce the number of interactions to as few as possible to complete each task.

In the initial development process, considering that this work will use Garmin smartwatches, the best app types were analyzed, and according to the documentation, the most suitable app type is a widget. It consists of a min-app that can be launched from the home screen and provides glanceable access to information. Moreover, it is a lightweight app type for the device, easy to use for the older adult, and includes all the technologies required for this project, such as BLE, background, sensor, and communications. The application is developed using the Connect IQ SDK, supported in the Monkey C programming language.

4.2.2. Design and development

The key concept in the design and development of the application is the association of the person's smartwatch with all the beacons installed inside the home. For this, when the application connects for the first time, it will fetch the unique identifier of the smartwatch with twenty-four hexadecimal digits and then send it to the API so that this code is created in the database. With this, it is possible to associate all beacons with that device.

To ensure security, a code associated with the application allows the device's configuration. This way, when the user introduces the 24-digit code, if it is correct, the application makes a GET request to the API with the identifier and some requests properties, such as verification token, origin, and device type, to receive the beacons information (UUID, MAC Address and location) to store it locally. After that, a message appears that the operation was successfully executed. An error message will appear on the smartwatch screen if the code is wrong or if something goes wrong during the configuration process. This entire configuration process is presented in **Figure 7**.

After this configuration, the user can access different options within the application. The first screen welcomes the user and suggests an interaction with the smartwatch to access them.

Figure 7. Smartwatch flow.

This interaction is to slide from right to left with a finger on the device's screen. A menu with four options will appear when performing this interaction, illustrated in the second image of **Figure 7**. With the first option, the user can check the last time the application communicated with the API to update the daily data of which beacons he read during the day, illustrated in the top row of the figure. The second option makes it possible to see the last measure of BPM. The third option lets the person see which beacons are associated with the device and their respective information. The previous option focuses on the configuration and installation of the application, presented at the beginning of this section.

5. Results

This section presents findings from the execution of tasks identified in **Table 1**. These results are based on the execution time of each task and the application of the UEQ after task completion.

Table 4 presents the average time (in seconds) for completing each task. As expected, results show that 85% of the time spent in the execution of tasks is related to the mobile application, while 15% is related to the smartwatch. For the configuration of a house with four rooms, the total time to execute the tasks is 62.2 s, mainly focused on the mobile application, to reduce interactions with the smartwatch. The smartwatch is a prominent wearable for daily living, covering tasks presented in the interaction results of rows 9–12 of **Table 4**.

As expected, the keyboard interaction related to the registration of the 24-digit code to pair the smartwatch and the system is the most costly regarding the relative total time of task execution (approximately 51% of the total time). However, this interaction is impossible to remove from the system, given that the pairing between these devices requires this process to be executed.

As mentioned, the UEQ is used to measure satisfaction parameters and is applied after user interface testing. The measured scale means are set concerning existing values from a benchmark data set. This data set contains data from 18483 persons from 401 studies concerning different types of products. The comparison of the results for the evaluated product with the data in the benchmark allows conclusions about the relative quality of the evaluated product compared to other products. To obtain the overall rating of applications, users were asked to fill out two forms: one related to the mobile application and the other related to the smartwatch.

Based on the UEQ scale benchmark, the mobile app's overall rating is excellent, and the smartwatch app varies from above average to excellent, as shown in **Table 5**, **Figures 8** and **9**.

Table 4. Interaction results.

No.	Relates to	Task	Average time (seconds)
1	Mobile app	To setup a beacon, find the textbox in the mobile application to insert the smartwatch code to pair both devices.	1.1
2	Smartwatch	Find the code in the smartwatch to be inserted in the mobile application.	2.8
3	Mobile app	Go to the mobile application to start to configure locations of beacons.	1.0
4	Mobile app	Insert the code from the smartwatch in the mobile application.	36.0
5	Mobile app	Select a beacon that is not yet configured.	1.5
6	Mobile app	Add a beacon to a room.	3.6
7	Mobile app	Configure all the remaining beacons (setting up 4 beacons).	15.3
8	Mobile app	Check if the house is fully configured.	1.3
9	Smartwatch	Check your average heartbeat.	1.4
10	Smartwatch	See how much time you have spent in the kitchen.	2.1
11	Smartwatch	See your sleep quality.	2.4
12	Smartwatch	Check the battery charge of the beacon in the kitchen.	2.2

Table 5. UEQ results for the overall rating of mobile and smartwatch applications.

Mean			Comparison to benchmark		Interpretation of results	
Scale	**Mobile app**	**Smartwatch**	**Mobile app**	**Smartwatch**	**Mobile app**	**Smartwatch**
Attractiveness	2.41	1.40	Excellent	Above average	Range of 10% best	25% better, 50% worse
Transparency	2.30	2.02	Excellent	Excellent	Range of 10% best	Range of 10% best
Efficiency	2.40	2.22	Excellent	Excellent	Range of 10% best	Range of 10% best
Control	2.00	1.90	Excellent	Excellent	Range of 10% best	Range of 10% best
Stimulation	1.97	1.50	Excellent	Good	Range of 10% best	10% better, 75% worse
Innovation	2.20	1.30	Excellent	Good	Range of 10% best	10% better, 75% worse

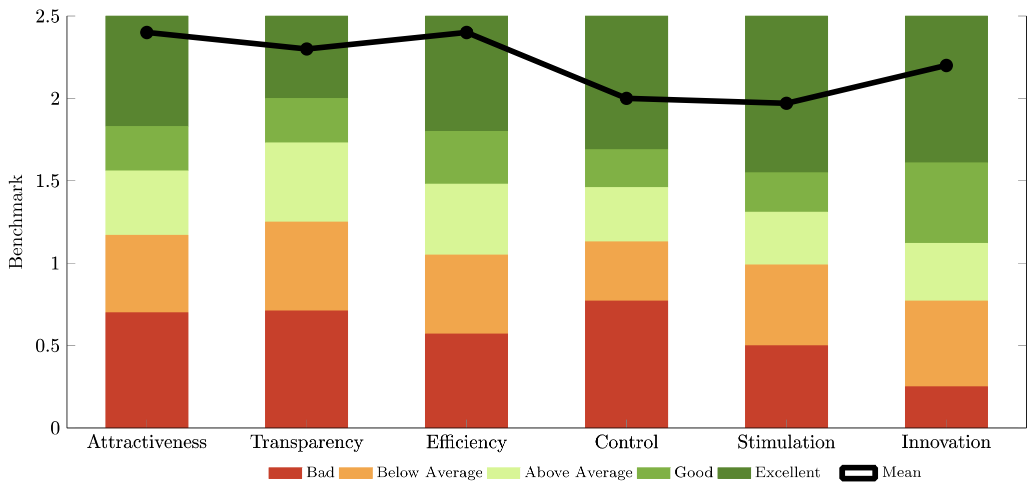

Figure 8. UEQ benchmark graph for the mobile application.

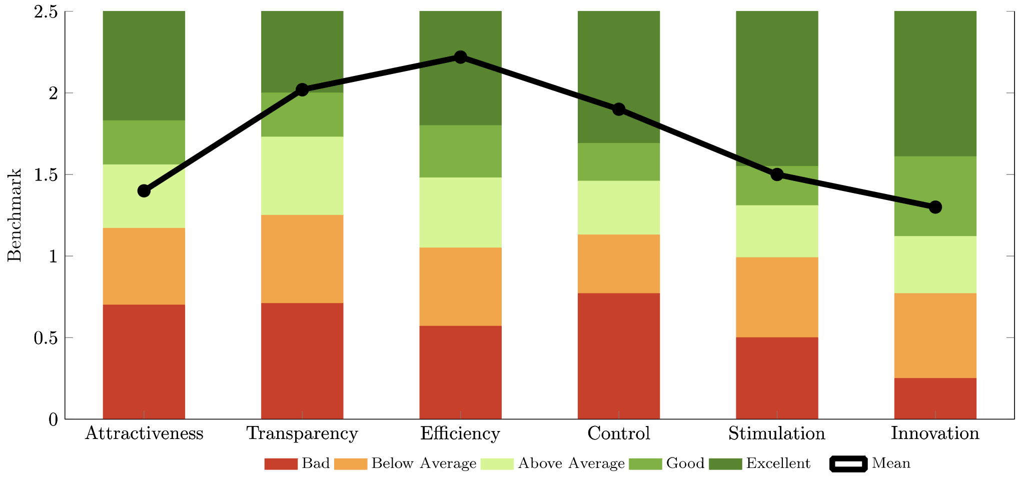

Figure 9. UEQ benchmark graph for the smartwatch application.

The evaluation differences can be easily explained. First, the design of smartwatch applications is complex since size restrictions associated with the hardware are a natural constraint when designing for older adults. Moreover, the Garmin guidelines and restrictions in the design for the Garmin Vivoactive 4 do not leave much margin for improvement. The optimal contrast and the size of elements in the application are not easy to obtain. However, it is essential to consider that the selected users did not have much proficiency in using mobile and smartwatch applications. If the excellent overall rating for the mobile app is not surprising, the interaction results with the smartwatch application are positively interpreted. Thereof, using the smartwatch application will improve the perception of the smartwatch system.

6. Conclusions

This paper presents the design of mobile and smartwatch applications for AAL systems. The goal is to set up an integrated environment where older adults can be autonomous in the configuration of the system, on their location, and also acquire biometric data. Considering that older adults tend to have difficulties in the identification of new symbolization related to the digital era, and the evolution of technology[55], a set of design guidelines were applied to the design of the mobile application, which was also mapped to the smartwatch application.

To validate the quality of the design, the UEQ was applied to both interfaces. Results show that users found the interaction to be excellent in all the parameters of the UEQ in the evaluation of the mobile interface. For the smartwatch application, results vary from above average to excellent. The lack of guidelines for the design of smartwatch applications for older adults leaves room for improvement as long as the UI smartwatch technologies allow the application of such guidelines.

Future work will follow two directions. First, at the level of interface design, guidelines for the design of smartwatch applications for older adults have to be developed, given the size restrictions of the devices. Next, the data gathered from the integrated system has to be analysed using statistical formulas and methods to detect patterns and outliers, using interpretability and explainability.

Author contributions

Conceptualization, RD and CC; methodology, RD; software, GA; validation, RD and CC; formal analysis, RD; investigation, GA; resources, RD; data curation, GA; writing—original draft preparation, GA; writing—review and editing, RD and CC; visualization, RD; supervision, RD; project administration, RD; funding acquisition, RD. All authors have read and agreed to the published version of the manuscript.

Funding

This work is funded by National Funds through the FCT—Foundation for Science and Technology, I.P., within the scope of the project Ref. UIDB/05583/2020. Furthermore, we would like to thank the Research Centre in Digital Services (CISeD), and the Polytechnic of Viseu for their support.

Conflict of interest

The authors declare no conflict of interest.

References

1. Covinsky KE, Palmer RM, Fortinsky RH, et al. Loss of independence in activities of daily living in older adults hospitalized with medical illnesses: Increased vulnerability with age. *Journal of the American Geriatrics Society* 2003; 51(4): 451–458. doi: 10.1046/j.1532-5415.2003.51152.x
2. Preece J, Sharp H, Rogers Y. *Interaction Design: Beyond Human-Computer Interaction*. John Wiley & Sons; 2015.
3. Nielsen J. *Usability Engineering*. Morgan Kaufmann; 1994.
4. ISO. *Ergonomics of Human-System Interaction—Part 210: Human-Centred Design for Interactive Systems*. ISO; 2019.
5. Neale DC, Carroll JM. The role of metaphors in user interface design. In: *Handbook of Human-Computer Interaction*. Elsevier; 1997. pp. 441–462.
6. Kwon LN, Yang DH, Hwang MG, et al. Automated classification of normal control and early-stage dementia based on activities of daily living (ADL) data acquired from smart home environment. *International Journal of Environmental Research and Public Health* 2021; 18(24): 13235. doi: 10.3390/ijerph182413235
7. van Kasteren Y, Bradford D, Zhang Q, et al. Understanding smart home sensor data for ageing in place through everyday household routines: A mixed method case study. *JMIR Mhealth Uhealth* 2017; 5(6): e52. doi: 10.2196/mhealth.5773
8. Caroux L, Consel C, Dupuy L, Sauzéon H. Towards context-aware assistive applications for aging in place via real-life-proof activity detection. *Journal of Ambient Intelligence and Smart Environments* 2018; 10(6): 445–459. doi: 10.3233/AIS-180505
9. Lach HW, Lorenz RA, Palmer JL, et al. Home monitoring to track activity and sleep patterns among older adults: A feasibility study. *Computers, Informatics, Nursing: CIN* 2019; 37(12): 628–637. doi: 10.1097/CIN.0000000000000569
10. Yu J, An N, Hassan T, Kong Q. A pilot study on a smart home for elders based on continuous in-home unobtrusive monitoring technology. *Health Environments Research & Design Journal* 2019; 12(3): 206–219. doi: 10.1177/1937586719826059
11. VandeWeerd C, Yalcin A, Aden-Buie G, et al. HomeSense: Design of an ambient home health and wellness monitoring platform for older adults. *Health and Technology* 2020; 10(5): 1291–1309. doi: 10.1007/s12553-019-00404-6
12. Wang Y, Yalcin A, VandeWeerd C. Health and wellness monitoring using ambient sensor networks. *Journal of Ambient Intelligence and Smart Environments* 2020; 12(2): 139–151. doi: 10.3233/AIS-200553
13. Austin J, Dodge HH, Riley T, et al. A smart-home system to unobtrusively and continuously assess loneliness in older adults. *IEEE Journal of Translational Engineering in Health and Medicine* 2016; 4: 2800311. doi: 10.1109/JTEHM.2016.2579638
14. Vildjiounaite E, Mäkelä SM, Keränen T, et al. Unsupervised illness recognition via in-home monitoring by depth cameras. *Pervasive and Mobile Computing* 2017; 38(1): 166–187. doi: 10.1016/j.pmcj.2016.07.004
15. Kim JY, Liu N, Tan HX, Chu CH. Unobtrusive monitoring to detect depression for elderly with chronic illnesses. *IEEE Sensors Journal* 2017; 17(17): 5694–5704. doi: 10.1109/JSEN.2017.2729594
16. Aramendi AA, Weakley A, Goenaga AA, et al. Automatic assessment of functional health decline in older adults based on smart home data. *Journal of Biomedical Informatics* 2018; 81: 119–130. doi: 10.1016/j.jbi.2018.03.009
17. Grgurić A, Mošmondor M, Huljenić D. The SmartHabits: An intelligent privacy-aware home care assistance system. *Sensors* 2019; 19(4): 907. doi: 10.3390/s19040907
18. Ghayvat H, Awais M, Pandya S, et al. Smart aging system: Uncovering the hidden wellness parameter for well-being monitoring and anomaly detection. *Sensors* 2019; 19(4): 766. doi: 10.3390/s19040766
19. Susnea I, Dumitriu L, Talmaciu M, et al. Unobtrusive monitoring the daily activity routine of elderly people living alone, with low-cost binary sensors. *Sensors* 2019; 19(10): 2264. doi: 10.3390/s19102264
20. Akl A, Snoek J, Mihailidis A. Unobtrusive detection of mild cognitive impairment in older adults through home monitoring. *IEEE Journal of Biomedical and Health Informatics* 2017; 21(2): 339–348. doi: 10.1109/JBHI.2015.2512273

21. Alberdi A, Weakley A, Schmitter-Edgecombe M, et al. Smart home-based prediction of multidomain symptoms related to alzheimer's disease. *IEEE Journal of Biomedical and Health Informatics* 2018; 22(6): 1720–1731. doi: 10.1109/JBHI.2018.2798062
22. Ault L, Goubran R, Wallace B, et al. Smart home technology solution for night-time wandering in persons with dementia. *Journal of Rehabilitation and Assistive Technologies Engineering* 2020; 7: 1–8. doi: 10.1177/2055668320938591
23. Ahamed F, Shahrestani S, Cheung H. Internet of things and machine learning for healthy ageing: Identifying the early signs of dementia. *Sensors* 2020; 20(21): 6031. doi: 10.3390/s20216031
24. De Miguel K, Brunete A, Hernando M, Gambao E. Home camera-based fall detection system for the elderly. *Sensors* 2017; 17(12): 2864. doi: 10.3390/s17122864
25. Lotfi A, Albawendi S, Powell H, et al. Supporting independent living for older adults; Employing a visual based fall detection through analysing the motion and shape of the human body. *IEEE Access* 2018; 6: 70272–70282. doi: 10.1109/ACCESS.2018.2881237
26. Hu Y, Zhang F, Wu C, et al. A wifi-based passive fall detection system. In: Proceedings of the ICASSP 2020—2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP); 4–8 May 2020; Barcelona, Spain. pp. 1723–1727.
27. Wang B, Guo L, Zhang H, Guo YX. A millimetre-wave radar-based fall detection method using line kernel convolutional neural network. *IEEE Sensors Journal* 2020; 20(22): 13364–13370. doi: 10.1109/JSEN.2020.3006918
28. Ding C, Ding Z, Wang L, Jia Y. A fall detection method based on K-nearest neighbor algorithm with MIMO millimeter-wave radar. In: Proceedings of the 2021 IEEE 6th International Conference on Signal and Image Processing (ICSIP); 22–24 October 2021; Nanjing, China. pp. 624–628.
29. Ruan W, Sheng QZ, Yao L, et al. HOI-Loc: Towards unobstructive human localization with probabilistic multi-sensor fusion. In: Proceedings of the 2016 IEEE International Conference on Pervasive Computing and Communication Workshops (PerCom Workshops); 14–18 March 2016; Sydney, Australia. pp. 1–4.
30. Lan G, Liang J, Liu G, Hao Q. Development of a smart floor for target localization with bayesian binary sensing. In: Proceedings of the 2017 IEEE 31st International Conference on Advanced Information Networking and Applications (AINA); 27–29 March 2017; Taipei, Taiwan. pp. 447–453.
31. Lima M, Morgado JF, Duarte RP. Low-cost embedded system for customer loyalty. In: Yang XS, Sherratt S, Dey N, et al. (editors). *Lecture Notes in Networks and Systems*, Proceedings of Sixth International Congress on Information and Communication Technology; 25–26 February 2021; Singapore. Springer Singapore; 2022. Volume 216, pp. 777–785.
32. Kim JY, Chu CH, Kang MS. IoT-based unobtrusive sensing for sleep quality monitoring and assessment. *IEEE Sensors Journal* 2021; 21(3): 3799–3809. doi: 10.1109/JSEN.2020.3022915
33. König A, Crispim Junior CF, Derreumaux A, et al. Validation of an automatic video monitoring system for the detection of instrumental activities of daily living in dementia patients. *Journal of Alzheimer's disease: JAD* 2015; 44(2): 675–685. doi: 10.3233/JAD-141767
34. Xia S, Liu Y, Yuan G, et al. Indoor fingerprint positioning based on Wi-Fi: An overview. *International Journal of Geo-Information* 2017; 6(5): 135. doi: 10.3390/ijgi6050135
35. De Blasio G, Quesada-Arencibia A, Garcia CR, et al. A protocol-channel-based indoor positioning performance study for bluetooth low energy. *IEEE Access* 2018; 6: 33440–33450. doi: 10.1109/ACCESS.2018.2837497
36. Long N, Lei Y, Peng L, et al. A scoping review on monitoring mental health using smart wearable devices. *Mathematical Biosciences and Engineering: MBE* 2022; 19(8): 7899–7919. doi: 10.3934/mbe.2022369
37. Ju W, Leifer LJ. The design of implicit interactions: Making interactive systems less obnoxious. *Design Issues* 2008; 24(3): 72–84. doi: 10.1162/desi.2008.24.3.72
38. Memon M, Wagner SR, Pedersen CF, et al. Ambient assisted living healthcare frameworks, platforms, standards, and quality attributes. *Sensors* 2014; 14(3): 4312–4341. doi: 10.3390/s140304312
39. Carbonell N. Ambient multimodality: Towards advancing computer accessibility and assisted living. *Universal Access in the Information Society* 2006; 5(1): 96–104. doi: 10.1007/s10209-006-0027-y
40. Al-Shaqi R, Mourshed M, Rezgui Y. Progress in ambient assisted systems for independent living by the elderly. *SpringerPlus* 2016; 5(1): 624. doi: 10.1186/s40064-016-2272-8
41. Kautz H, Fox D, Etzioni O, et al. An overview of the assisted cognition project. *American Association for Artificial Intelligence* 2002.
42. Kientz JA, Patel SN, Jones B, et al. The Georgia Tech aware home. In: Proceedings of the CHI EA '08: CHI '08 Extended Abstracts on Human Factors in Computing Systems; 5–10 April 2008; Florence, Italy. pp. 3675–3680.
43. Cook DJ, Youngblood M, Heierman EO, et al. MavHome: An agent-based smart home. In: Proceedings of the First IEEE International Conference on Pervasive Computing and Communications (PerCom 2003); 26 March 2003; Fort Worth, TX, USA. pp. 521–524.
44. Lotfi A, Langensiepen C, Mahmoud SM, Akhlaghinia MJ. Smart homes for the elderly dementia sufferers: Identification and prediction of abnormal behaviour. *Journal of Ambient Intelligence and Humanized Computing* 2012; 3(3): 205–218. doi: 10.1007/s12652-010-0043-x

45. Bal M, Shen W, Hao Q, Xue H. Collaborative smart home technologies for senior independent living: A review. In: Proceedings of the 2011 15th International Conference on Computer Supported Cooperative Work in Design (CSCWD); 8–10 June 2011; Lausanne, Switzerland. pp. 481–488.
46. Rocha A, Martins A, Freire Junior JC, et al. Innovations in health care services: The CAALYX system. *International Journal of Medical Informatics* 2013; 82(11): e307–e320. doi: 10.1016/j.ijmedinf.2011.03.003
47. Wolf P, Schmidt AP, Klein M. SOPRANO—An extensible, open AAL platform for elderly people based on semantical contracts. In: Proceedings of the 3rd Workshop on Artificial Intelligence Techniques for Ambient Intelligence (AITAmI'08), 18th European Conference on Artificial Intelligence (ECAI 08); 21–22 July 2008; Patras, Greece.
48. Rivero-Espinosa J, Iglesias-Pérez A, Gutiérrez-Dueñas JA, Rafael-Palou X. SAAPHO: An AAL architecture to provide accessible and usable active aging services for the elderly. *ACM SIGACCESS Accessibility and Computing* 2013; (107): 17–24. doi: 10.1145/2535803.2535806
49. Rieman J, Franzke M, Redmiles D. Usability evaluation with the cognitive walkthrough. In: Proceedings of the Conference Companion on Human Factors in Computing Systems (CHI '95); 7–11 May 1995; Denver Colorado, USA. pp. 387–388.
50. Schrepp M, Thomaschewski J, Hinderks A. Design and evaluation of a short version of the user experience questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence* 2017; 4(6): 103–108. doi: 10.9781/ijimai.2017.09.001
51. Boivie I, Aborg C, Persson J, Lofberg M. Why usability gets lost or usability in in-house software development. *Interacting with Computers* 15(4): 623–639. doi: 10.1016/S0953-5438(03)00055-9
52. MongoDB. Available online: https://www.mongodb.com (accessed on 2 May 2023).
53. Adam S, Mukasa KS, Breiner K, Trapp M. An apartment-based metaphor for intuitive interaction with ambient assisted living applications. In: Proceedings of People and Computers XXII Culture, Creativity, Interaction; 1–5 September 2008; Liverpool, UK. pp. 67–75. doi: 10.14236/ewic/HCI2008.7
54. Kalimullah K, Sushmitha D. Influence of design elements in mobile applications on user experience of elderly people. *Procedia Computer Science* 2017; 113: 352–359. doi: 10.1016/j.procs.2017.08.344
55. Johnson J, Finn K. *Designing User Interfaces for an Aging Population: Towards Universal Design.* Morgan Kaufmann; 2017.
56. Ide android studio. Available online: https://developer.android.com/studio (accessed on 17 May 2023).
57. Kotlin programming language. https://developer.android.com/kotlin (accessed on 17 May 2023).
58. Material design. Available online: https://m3.material.io (accessed on 17 May 2023).
59. Figma: The collaborative Interface Design Tool. Available online: https://www.figma.com (accessed on 17 May 2023).
60. Morville P, Rosenfeld L. *Information Architecture for the World Wide Web: Designing Large-Scale Web Sites*, 3rd ed. O'Reilly Media; 2007.
61. Czaja SJ, Boot WR, Charness N, Rogers WA. Designing for Older Adults: Principles and Creative Human Factors Approaches. CRC Press; 2019.