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Design and usability assessment of a multi-device SOA-based telecare framework for the elderly

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***Abstract*—Telemonitoring is a branch of telehealth that aims at remotely monitoring vital signs, which is important for chronically ill patients and the elderly living alone. The available standalone devices and applications for the self-monitoring of health parameters largely suffer from interoperability problems; meanwhile, telemonitoring medical devices are expensive, self-contained, and are not integrated into user-friendly technological platforms for the end user.**

This work presents the technical aspects and usability assessment of the telemonitoring features of the HEREiAM platform, which supports heterogeneous information technology systems. By exploiting a service-oriented architecture (SOA), the measured parameters collected by off-the-shelf Bluetooth medical devices are sent as XML documents to a private cloud that implements an interoperable health service infrastructure, which is compliant with the most recent healthcare standards and security protocols. This Android-based system is designed to be accessible both via TV and portable devices, and includes other utilities designed to support the elderly living alone.

Four usability assessment sessions with quality-validated questionnaires were performed to accurately understand the ease of use, usefulness, acceptance, and quality of the proposed system. The results reveal that our system achieved very high usability scores even at its first use, and the scores did not significantly change over time during a field trial that lasted for four months, reinforcing the idea of an intuitive design. At the end of such a trial, the user experience questionnaire achieved excellent scores in all aspects with respect to the benchmark. Good results were also reported by general practitioners who assessed the quality of their remote interfaces for telemonitoring.

***Index Terms*—Telemonitoring, Interoperability, Bluetooth, Android, m-health, Elderly**

I. Introduction

TELEcare utilizes information and communication technologies (ICTs) to provide health and social care support to vulnerable users [1] that suffer from economic, social, health, or age-related conditions by helping them sustain independent living in their own homes. Telecare widens the horizons of telehealth to include more than just health services. It complements, rather than replaces, the current care model [2] and addresses the risks associated with providing such services outside clinical settings [3].

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Telecare systems represent a technology-enabled solution to assist the elderly in their daily routine, sustain independent living, and prevent complications [4]. Health telemonitoring features embedded into these systems reduce the number of physical clinic visits, while ensuring more control over the health of the subject. Nevertheless, several barriers still hamper the deployment of these services among older aged groups [5]. Initially, the requirements and technological literacy of older adults were not considered when designing the majority of these self-monitoring systems because the systems were not targeted for the elderly. From the viewpoint of *technogenarians*, such older adults can create, use, and adapt technologies to tackle health and illness in their daily lives [6]. However, despite such technology-savvy elderlies being able to actively utilize telecare systems entrusted to them, most of the other elderly show little or no understanding of the technology that is provided to them, leading to misuse and neglect of that technology [7]. This is an aspect of the so-called *digital divide*, i.e., the gap between those who utilize and have effective access to ICTs and those who do not [8]. This motivates the development of technologies for independent living and social participation geared toward older adults, which is often referred to as gerontechnology (www.gerontechnology.info).

From a technological perspective, telecare systems are usually closed and work only with a set of specific medical devices from a single vendor. Consequently, many telemonitoring medical devices are designed to be self-contained and employ in-house proprietary communication protocols and data definitions. Because of interoperability problems arising from proprietary solutions, they cannot be easily integrated into a clinical information system [9]. These aspects hamper the utilization of the full potential of these systems, including their economical and health benefits, because correct usage enables the collected information to be integrated into the care pathways, thereby tailoring the provided care and reducing hospital admissions and costs [1]. Interoperability problems are exacerbated in large-scale integrated digital health infrastructures at national and international level, where multiple organizations are involved and specific standards should be considered [10].

Based on these considerations, in a preliminary work [11] we presented HEREiAM, a flexible and extendable tele-social-care platform, expressly designed for the elderly. HEREiAM is capable of assisting older adults in the comfort of their own homes by providing a specific set of digital services. The care offered by HEREiAM is highly personalizable, organized around the needs of the elderly, and focused on promoting

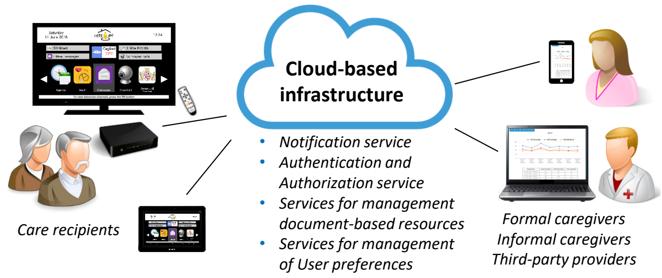

Fig. 1. General overview of the HEREiAM system.

independence, enhancing quality of life and ensuring emotional well-being and social contacts. The system is based on an Android framework designed to be accessible on TV and mobile devices, exploiting a user-centred design approach.

In this work, we present in detail the telehealth features embedded in the flexible HEREiAM platform, supporting data acquisition from different Bluetooth medical devices, and their transmission to a remote monitoring infrastructure, which is developed to include all the relevant security and interoperability features [12]. Such an approach enables a real integration of the telecare system into an appropriate health information flow [13]. To the best of our knowledge, there are no other platforms including all the characteristics featured by HEREiAM, neither on the market nor for research purposes. In order to assess the usability of the proposed telecare system, the outcomes of three evaluation sessions with older adults are presented. The first two, which are mainly aimed at investigating the perceived usability of the system after a first-time approach, explore the tablet and TV-based versions of the system, whereas the third is focused on the overall satisfaction of the users with the use of the TV-based solution in their homes, over a four-month longitudinal pilot study. Validated instruments for the usability assessment were adopted to enable future benchmarking with similar systems, tested in analogous conditions and with users effectively representing the target population for this kind of systems. Moreover, such an approach enables a quantitative and objective assessment with respect to ad-hoc custom methods. The opinions of general practitioners (GPs) on the system were also collected to evaluate its usefulness, usability, and security from a professional perspective.

II. The HEREiAM telecare system architecture

HEREiAM was presented in [11] as an innovative telecare system with high potential for improving the care of elderly people at home. Fig. 1 shows the architecture of the HEREiAM system. It is based on three domains that interact by exchanging and using services, information and documents: a home-care environment, a cloud-based infrastructure and a web portal at the disposal of caregivers and third-party service providers.

The *home-care environment* is organized around a specific set of digital services, which covers two important pillars of active aging: health and participation [14]. The current prototype of the HEREiAM system enables the elderly to:

- make and receive video calls within a personalized network of caregivers, view newspapers and discover local events, reducing the sense of isolation and loneliness associated with increasing age;
- use a digital agenda, get notifications for upcoming appointments, get reminder messages for medication intake, access a grocery shopping service from home and get products delivered right to the door, prolonging expectation of an autonomous and independent life;
- self-monitor and share key physiological parameters, gaining more knowledge and control over their personal health status.

Furthermore, the home-care environment includes also a set of environmental sensors installed in each room of the house, to sense the movements of the users during the day, thus giving authorized informal care-givers a means to access the data collected and understand possible anomalies.
As described previously, the elderly can access these services through tablets or television devices. This approach gives them the freedom to interact with the different services using the user interface (UI) that best suits their requirements, preferences, and lifestyles. In fact, as learned from the focus groups held during the system development, the use of a TV and a standard remote control is expected to promote the system's acceptance in home environments, overcoming the digital divide suffered by aged people [15]. Conversely, the tablet version with a touchscreen interface may be preferred by technogenarians, and would also support the out-of-home mobility of care recipients without significant differences, compared with the TV-based setting. Because of the aforementioned problems that might influence the user acceptance of technology, the home-care environment was developed following the principles of a user-centered design and elderly-friendly user interfaces, as in similar previous works [16]. These key features represent just the starting point of what HEREiAM can offer. The proposed system is open and enables the integration of new services and new devices as the need arises.

The *cloud-based infrastructure* centralizes the users' profile management and implements the following interoperability services:

- authentication and authorization service, which provides secure and role-based access to the system and its content (services and resources);
- services for managing document-based resources, which provide controlled access, management functionalities and interfaces to manage the information stored on the cloud in documental format;
- notification services, which allow the user to send notifications to one or more services and/or to subscribe to specific notification channels;
- services for management of user's preferences.

A *web portal*, accessible from any Internet-connected device, provides pre-authorized caregivers and third-party service providers with access to documents, data, information, and services of the cloud-based infrastructure. It is built with a wide selection of additional functionalities, which support:

- the creation of contents, such as text messages, videos, appointments, shopping list, and the possibility to make that content available to care recipients on their TV or tablet;
- the monitoring of the availability of the offered services and the collection of statistics related to their usage (i.e., number of times each service was used, total time and the mean time of usage by the single participant, etc.);
- the access to up-to-date and meaningful information about care recipients at home which are stored in the cloud-based infrastructure.

In this section, we provide full details on all these three components, with a focus on the health telemonitoring functionality of the system, which is the most critical in terms of complexity, security and usability. A specific *Health app* was included to provide health telemonitoring features, enabling the system to communicate with several personal medical devices (such as body weight scales and noninvasive blood pressure meters) using standard Bluetooth technology and to interface with a cloud-based telecare infrastructure. The cloud-based infrastructure will first be described for clarity, because some of the implementation choices at the level of the Health app are specified by the software infrastructure specifications. Then, the Health app will be presented with details about measurement management and document creation, and finally, the part of the web portal at the disposal of professional caregivers' will be described.

A. Cloud-based telecare infrastructure

The telecare software infrastructure is based on a service-oriented architecture (SOA) [17], implemented through web services that use a document-oriented interaction model for data exchange. Such an approach is widely accepted in healthcare for the development of information systems [18] and has been also used in several ambient assisted living projects [19]. The SOA services interact through structured documents, typically XML or JavaScript object notation (JSON) documents. In the proposed system, XML-type documents were chosen because of their large diffusion in healthcare [20], even with extensions targeting home healthcare applications [21].

Each document, with its metadata, is characterized by its owner, context, accountability, and purpose, considering both the document and its content. A shared organizational model has been defined to determine the documents that must be shared, those authorized to generate the documents, those who may access them, the procedures to publish and retrieve documents, and the engagement rules among the actors. To provide such features, the telecare software infrastructure comprises the following:

- an archiving system based on the registry/repository pattern to manage documents;
- an identity cross-reference system to manage and identify entities and to enable data exchange among different systems;
- systems profiling and notification management to define engagement rules required by the organizational model;
- a user identification and profiling system; and
- an enterprise service bus (ESB) at infrastructural level to proxy and mediate platform services.

To address interoperability requirements and facilitate service reuse, the software infrastructure was developed in accordance with a subset of the integration profiles of the integrating the healthcare enterprise (IHE) initiative (i.e., Cross-Enterprises Documents Sharing (XDS.b), Patient Identifier Cross-Referencing (PIX), Patient Demographics Query (PDQ) and Document Metadata Subscription (DSUB)) and the use of standard services specified by the healthcare service specification project (HSSP). In particular, the Retrieve, Locate, and Update Service (RLUS) for document management and the Identity Cross-Reference Service (IXS) for entity management were adopted. To support bidirectional information exchange between end-user devices such as low-end commercial tablets and smartphones and Healthcare Information Systems, a noteworthy two-way bridge between HSSP, RLUS, and IHE XDS.b was implemented.

1) Internet interface: The software infrastructure was deployed on a private cloud and delivered as Software as a Service (SaaS). It was accessible via the Internet; thus, the infrastructure could be accessed by both end-user devices and all the enabled stakeholders involved in the older-adult care workflows. Because all the health-related information was sensitive, they were made accessible only via the widely used HTTPS communication protocol to protect data exchange.

A web server was configured to be the unique access point for requests arriving from the Internet, thereby proving to be the best practice to improve security and socket-handling/system stability. The Apache HTTP server was the implemented web server.

All the implemented web services were orchestrated by an ESB. The feature-rich and standards-compliant WSO2 ESB (https://wso2.com) [22] was the selected open-source provider for the proposed telecare system, which was the access point for all the web services. The WSO2 ESB handled message routing, mediation, and distribution to destination services. Moreover, the ESB mediated the service access authentication and authorization by integrating with the open-source WSO2 identity server [23], which implements the representational state transfer security with OAuth2.0 (https://oauth.net/2) and OpenID Connect (https://openid.net). Furthermore, the chosen identity server also supports a role-based access control and fine-grained policy-based access control via Extensible Access Control Markup Language (XACML).

B. The Health app

The Health app was developed in Java for Android, and it can be installed in all devices with at least Android platform version Ice Cream Sandwich 4.0, API Level 14 (targeting approximately 94% of total Android devices [24]). In this work, the application was installed onto two hardware platforms: an Android X8-H Plus mini-PC (by MiniX Ltd, South San Francisco, CA, USA) and a Samsung Galaxy Note 10.1 tablet (by Samsung Group, Seoul, South Korea). The mini-PC was embedded into a custom set-top box to hide the external peripherals required for proper operation, such as

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Fig. 2. The HEREiAM TV-based telecare system with the main screen of the Health app.

```
<soap:Envelope xmlns:soap="…">
<soap:Header/>
<soap:Body>
<PutRequest xmlns:="…">
<document xmlns:="…">
    <metadata>
    …
    </metadata>
    <payload>
        <record>
        …
        </record>
    </payload>
</document>
…
</PutRequest>
</soap:Body>
<soap:Envelope>
```

Fig. 3. Structure of an XML file containing a weight measurement.

a 4G LTE M7350 Wi-Fi router (by TP-Link Technologies Co., Ltd., Shenzhen, China) to be provided to users without a Wi-Fi Internet connection, an infrared USB receiver for remote control, and an ACR38U-N1 PocketMate Smart Card Reader (by Advanced Card Systems Ltd., Hong Kong) for password-free user authentication and login in association with an ACOS3-32 microcontroller smartcard (Fig. 2). As input devices, the two hardware platforms support the touch screen for the tablet and a custom remote control for the mini-PC [11].

In both cases, the user interface comprises a title bar at the top of the screen (which displays the name of the running activity, the current date, and time), the current page content in the middle of the screen, and a bottom bar with standard navigation buttons (back and home). The current page content varies according to the running activity. In the first activity (main screen) of the Health app, represented in Fig. 2, the user can choose between different medical devices to perform a physiological measurement. At the time of writing, the application could collect data from different Bluetooth sphygmomanometers and weight scales, while glucometers and pulse oximeters are currently being integrated.

When the chosen medical device is selected by tapping or using the navigation arrows in the remote control followed by pressing the OK button, a screen with instructions to support the user in the measurement process appears. This screen comprises a trigger for an activity that manages the Bluetooth connection with the selected device and the acquisition of the measurement result. The Health app waits in this activity until data are received.

Once the user completes the measurement, the results are automatically displayed on a new screen, and it is possible to send this data to the cloud. If the users mistakenly presses the Back or Home navigation buttons, the application asks their confirmation before exiting, which leads to losing the collected data.

For users suffering from chronic diseases that require some measurements at a fixed time of the day, the application can also generate a reminder. Furthermore, messages sent from the caregivers through the telecare system will automatically show up every time the user opens the Health app, blocking any measurement activity until the messages have been read.

1) Documents Creation and Management: For each measurement, a structured XML file is created and sent to the server without being stored inside the Android tablet or digital TV box. The generic XML schema of a file containing the measurement result of the patient's is shown in Fig. 3.

The file contains an envelope element that identifies it as a Simple Object Access Protocol (SOAP) message, a header (reserved for future use), and a body element containing the information required for the receiving server, as well as the data of the patients. The measurement and identification data of the patients are saved in the document element of the XML, which contains metadata and payload. In the document element, there are three records for the blood pressure (systolic, diastolic, and pulse values), and one for the body weight.

To be compliant with the cloud-based telecare infrastructure and reduce the burden for the app developers, some external services have been created. In particular, to send the data that the app collected from the connected medical devices, a ServiceProxy has been developed, which can call the remote services implemented in the private cloud. The ServiceProxy component is implemented as an Android service, and it does not provide any user interface. The first step for the app is to bind to the ServiceProxy invoking the

```
connect(clientid, clientsecret)
```

interface with parameters that uniquely identify the app. When the application is successfully connected, it can invoke the remote services without worrying about user authentication and authorization, because the ServiceProxy handles the associated activities. Meanwhile, this improves security by eliminating the need to store usernames and passwords in the app as well as any personal data of the patient. After the connection, the application can call a specific method to send the collected data, which will then be transparently formatted in XML documents as described and sent over the Internet.

2) Measurement Management: The Health app was developed to be compliant with different medical devices, using

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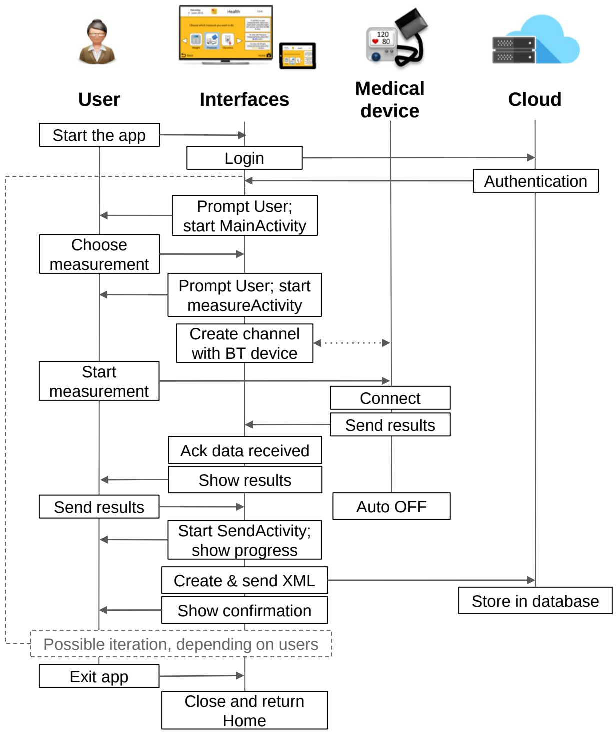

Fig. 4. Interaction model among the actors in the system.

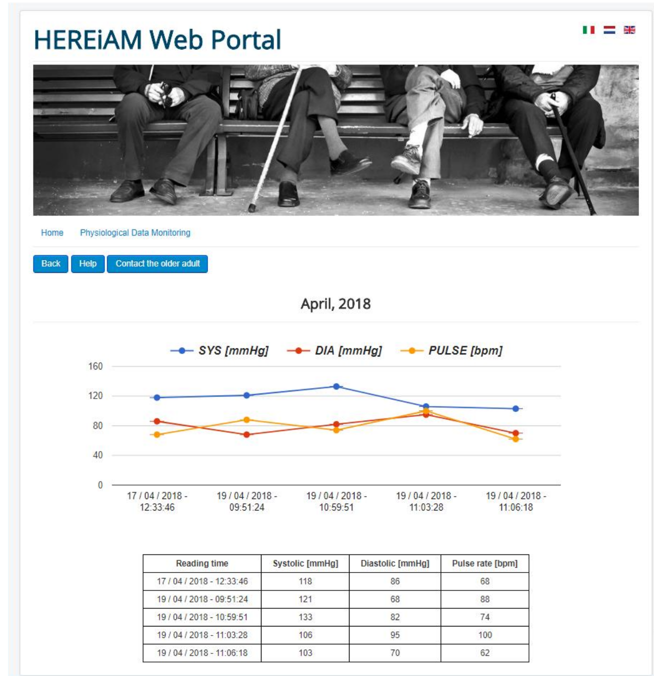

Fig. 5. Web Portal interface displaying blood pressure records.

either the serial port profile (SPP) or the health device profile (HDP) of the Bluetooth standard [25]. The SPP is based on the radio frequency communication (RFCOMM) protocol and allows the transmission of data encoded in a proprietary and manufacturer-specific format. The HDP operates in conjunction with the IEEE 11073 protocol and allows interoperability between medical, healthcare, and fitness applications from different manufacturers. For now, the monitoring system can communicate with the following medical devices (by A&D Australasia Pty Ltd., Sydney, Australia): the UA-767PBT, UA-767PBT-C, and UA-767PBT-Ci sphygmomanometers and the UC-321PBT, UC321-PBT-C, and UC-355-PBT-Ci weight scales. The PBT series only supports the SPP and works in master mode. In this case, the device starts the connection process only at the end of the measurement. To connect and exchange data with PBT devices, the application creates a server socket that listens for incoming connection requests. The integration of devices of the PBT series requires agreements with the manufacturer to collect the data (because the protocol is not disclosed) as well as some customizations at the app level. The PBT-Ci series supports both SSP and HDP. It can work in master or slave mode, and it is able to connect with the application immediately after the medical device has been turned on. Finally, the PBT-C series only supports HDP. To connect with it, an HDP activity has been created, following the guidelines of Android developers [26].

Considering all the provided information, Fig. 4 summarizes the interaction process between the patient, the medical devices, the Android application, and the private cloud implementing the telemonitoring infrastructure. Obviously, provided that a Bluetooth communication support is available, also custom medical devices for the management or treatment of age-related diseases can be interfaced with the system, exploiting its functionalities for medical data acquisition and secure transmission/exchange [27], [28].

C. The caregivers' portal

All the XML documents generated by the application and saved on the cloud are available for the users' GPs through the caregivers' portal. The caregivers' portal is a web interface designed in PHP and MySQL database integration within Joomla framework to involve the caregivers in the care process of older adults through the proposed system. It can be used by family members and informal and professional caregivers to access the data generated and saved by the elderly through the Health app. It has been designed to be simple and intuitive, with only the important information highlighted. The main page allows selection of the subject to be monitored, the physiological measurement of interest, and the observation interval. After the selection, the system performs a query to the database, uploading the results on a new web page (e.g. Fig. 5 shows trends of recorded blood pressure data). This web page presents a line chart that shows the trend of records over time, which is usually more significant than the individual measurements, and a table containing the details of each record. From the portal, the caregivers are able to send feedbacks about the measurements trend in form of text messages to their care recipients. Such a messaging service is unidirectional from caregivers to patients; thus, no incoming messages from the patients can be received through the portal.

III. Usability assessment methods

A. Field trials

Three different aspects were investigated to evaluate the usability of the different components of the proposed monitoring system:

- the usability of the Health app at a first approach with the system (short term),
- the usability after some months of use (medium term), and
- the usability of the caregivers' portal by GPs.

1) System usability in the short term: To assess the experiences of first-time users with the Android application, two groups of older adults, randomly chosen from all the patients of a public health clinic in Italy, were involved in several test sessions. The interviews were anonymous, and according to the Italian Legislative decree (Art. 13 n. 196/2003), no personal data was recorded, and neither any clinical measurements were performed. One session was dedicated to investigate the usability of the TV-based solution, whereas the other to test the tablet-based version of the system. In both sessions, the inclusion criteria were limited to an age above 65 years, while exclusion criteria were the presence of physical impairment hampering the normal use of the system and declared cognitive deficits. All participants were informed about the aim of the study and the functionalities of the application, and they chose the device to use. Participants were asked to start the Health app, start the weight measurement by weighing a bag to simulate the acquisition of their own weight, send the results to the cloud, and analyze the feedback of the physician sent through a fake message to the application. The A&D UC-321PBT weight scale was used.

To better understand the results obtained during the tests, both sample groups were profiled according to age, education, and interaction with some technologies. All subjects were interviewed to find out how often they watch TV, how often they use a mobile phone, a computer, a tablet, and some medical devices to measure their vital signs.

The evaluation of the TV-based version of the system involved a sample of 28 patients (14 males and 14 females) aged 79 ± 6 years (67–93). Regarding education, three of them had a primary school certificate, 22 had a high-school diploma, and three had a university degree.

The evaluation of the tablet-based version of the system involved a sample of 12 patients (4 males and 8 females) aged 75 ± 6 years (65–83). Regarding education, three of them had a university degree, five had a high-school diploma, and the remaining four had a primary school certificate.

As shown in Fig. 6, in both samples almost all participants watched TV and used computers every day, and less than half used mobile phones often, while the majority of them never used a tablet. Approximately half of them often used technology to check their health status. The differences between groups are not significant ($p < 0.05$).

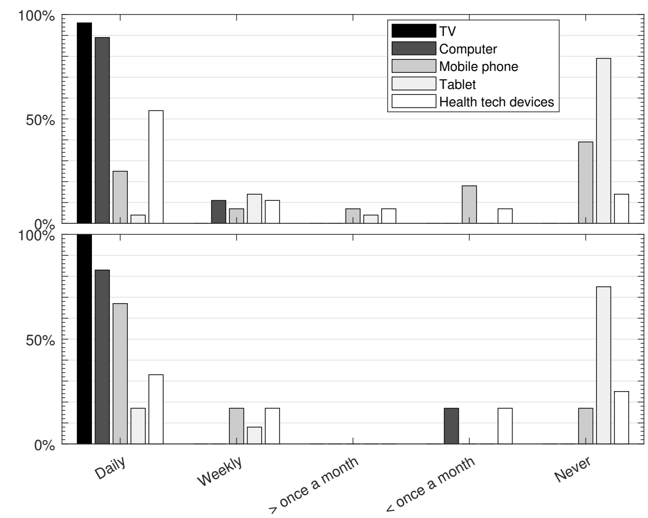

Fig. 6. Technologies usage survey results on the group testing the TV-based version of the system (top) and the tablet-based version (bottom).

2) System usability in the medium term: For the medium-term evaluation, in a more realistic application scenario, the TV-based monitoring system was incorporated in the daily lives of 19 older adults (8 males, 11 females) aged 73 ± 6 years (65–87) for a period of four months in an investigative longitudinal pilot study. Most subjects reported a regular intake of drugs for chronic conditions (75%) and health problems in the previous six months (80%). Educational level: 15% completed primary school, 40% completed middle school, 30% completed high school, and 15% graduated from higher institutions.

The sample group was recruited for the study from among the subjects enrolled in the Social Services Department activities in an Italian municipality. The inclusion criteria were the following: age of over 65 years, ability to live independently and to engage in normal verbal communications, and familiarity with basic TV functionalities. Exclusion criteria were any kind of cognitive impairments or serious visual or hearing impairments and any severely limited dexterity in one or both hands. The study was performed following the principles outlined in the Helsinki Declaration of 1975, as revised in 2000. Subjects were informed about the aim of the study, and they provided their informed consents. No clinical evaluation on the transmitted data was performed, and no data was stored in the cloud-based infrastructure for future use. All subjects used the system as a form of health self-monitoring device, with the possibility of enjoying all the additional services provided by the system.

During the home installation procedure of the system, the participants received a personal smart card for password-free authentication and the user manual, and they were shown a system demonstration. The A&D UA-767PBT-Ci sphygmomanometer and the A&D UC-355-PBT-Ci weight scale were configured and connected to the Android TV box via Bluetooth. Internet connection was configured to work with the broadband Wi-Fi facilities of the user or when not available, by an internal modem.

3) Caregivers' portal usability: The caregivers' portal usability was evaluated with a group of seven GPs (three males and four females) aged 41 ± 13, selected by convenience

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sampling in the same municipality where the medium-term field trial was programed, in the urban districts with the largest number of elderly people. All GPs declared that they already used ICT systems for the management of their patients. Each GP had the opportunity to

- watch a short video explaining the overall working principle of the HEREiAM system and the Health app in particular (including an explanation of how the elderly interact with the system);
- watch a short video describing the caregivers' portal; and
- explore the caregivers' portal and choose one virtual patient from a list and view the corresponding measurement trend.

B. Field trials evaluation methodology

Based on the aspects to be evaluated, different tools and methods for data collection and analysis were used.

1) Evaluation methodology for the short-term tests: For the short-term tests, two quality-validated questionnaires were adopted to measure the usability of the TV- and tablet-based versions of the monitoring system as well as the user-perceived satisfaction: the *System Usability Scale* (SUS) [29] and the *Post-Study System Usability Questionnaire* (PSSUQ) [30].

The former, which is based on 10 statements to be rated, provides a usability score between 0 and 100: the higher the SUS scores, the higher the perceived usability. The latter comprises 19 statements (statements 9 and 10 were excluded because they were inapplicable) generating scores from 1 to 7 (the lower the better) on three different aspects of the system: usefulness, information quality, and interface quality. An overall score can also be computed as the average of all the statements scores.

2) Evaluation methodology for the medium-term tests: All subjects who participated to the medium-term trial were asked to fill in two questionnaires: the SUS and the *User Experience Questionnaire* (UEQ) [31]. Both questionnaires were completed on two occasions during the study: once in Month 2 (T_1) and once after the end of the intervention, i.e., Month 4 (T_2), to investigate any change in the participants perception of the system over time.

The UEQ comprises 26 pairs of antithetic adjectives as a part of the question, which focus on six aspects: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. For each aspect, the scale ranges from -3 (most negative answer) to $+3$ (most positive answer). The UEQ comprises a complete data analysis tool including a benchmark data set (www.ueq-online.org), which allows for a more sensible judgment about the quality of a product, given the obtained scores. The benchmark contains user experience results from 246 product evaluation studies with the UEQ (with a total of 9905 participants in all evaluations), concerning various products, using five categories to distribute item scores from "Bad" to "Excellent".

3) Evaluation methodology for the caregivers' portal test: To assess the quality of the proposed caregivers' portal from the perspective of the GPs, two usability questionnaires, *Website Quality* (WQ) [32] and *WebQual 4.0* [33], and a semi-structured interview were used.

TABLE I
COMPARISON OF THE SUS AND PSSUQ SCORES OBTAINED DURING THE SHORT-TERM ASSESSMENT OF THE HEALTH APP.

	TV-based	**tablet-based**	***p*-value**
SUS score	84 ± 13	81 ± 12	0.54
PSSUQ score	1.5 ± 0.5	1.4 ± 0.4	0.53

The WQ comprises 25 questions (two questions related to customer policies and services were ruled out because they were inapplicable) and measures four different aspects of a website: technical adequacy, content quality, specific contents, and appearance. The score ranges from 1 to 7 (the higher the better).

The WebQual 4.0 comprises 23 questions, evaluating three different aspects of a website: usability, information quality, and service interaction. The score ranges from 1 to 7 (the higher the better).

The semi-structured interview comprises 12 open questions (provided in Appendix), developed by expert psychologists, to gain more insight on the system from the perspective of the GP.

4) Statistical analysis: The statistical analysis was performed using STATA 15 (StatCorp., Austin, TX, USA). The differences in the SUS scores in the samples for the tests were tested by Student's t-test. The ANOVA analysis with Bonferroni adjustment was used to compare average scores across three categories for PSSUQ and six item categories for UEQ. The association between the usability scores, age, gender, education, and frequency of ICT usage in the short-term assessment and that between age, gender, education, medicine consumption and diseases, and usability scores in the medium term was evaluated with Pearson correlation coefficient. All statistical tests were two-sided, and a p value of < 0.05 was considered significant.

IV. EXPERIMENTAL RESULTS

A. Health app usability

The descriptive statistics of the SUS and PSSUQ scores for the short-term assessment are shown in Table I. All evaluations achieved good scores. This suggests that the perceived usability of the application is quite high regardless of the interface used (tablet or TV), because there was no significant difference between the two interfaces with different scales.

The SUS score for the short-term assessments with TV is inversely associated with age ($r = -0.71$, $p < 0.001$) for both males and females $r = -0.62$, $p = 0.018$; $r = -0.82$, $p = 0.0003$, respectively), and positively associated with the frequency of PC use ($r = 0.40$, $p = 0.03$). These results confirm that the first-time use of the device, even if simple, is influenced by the computer literacy and age of the subject, which are usually interdependent factors. Moreover, the SUS scores in the group with tablet were positively associated with educational level ($r = 0.66$, $p = 0.021$) and with the frequency of tablet use ($r = 0.83$, $p = 0.0008$), which suggests that more skills are required to adopt this interface compared with the TV-based version. Only in females, the SUS score is inversely

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TABLE II
DETAIL OF THE PSSUQ ITEM CATEGORY RESULTS (MEAN AND STANDARD DEVIATION) OBTAINED DURING THE SHORT-TERM ASSESSMENT.

PSSUQ category	**TV-based**	**tablet-based**	***p*-value**
System Usefulness	1.9 ± 0.8	1.5 ± 0.6	0.21
Information Quality	1.2 ± 0.4	1.1 ± 0.4	0.49
Interface Quality	1.3 ± 0.5	1.6 ± 0.8	0.19
***p*-value**	0.0004	0.159	

TABLE III
SUS AND UEQ SCORES (MEAN AND STANDARD DEVIATION) OBTAINED FROM THE MEDIUM-TERM TRIAL, AT T_1 AND T_2, FOR THE TV-BASED SYSTEM.

	T_1	**T_2**	***p*-value**
SUS score	80 ± 17	82 ± 13	0.58
UEQ Attractiveness score	2.1 ± 0.6	2.2 ± 0.7	0.61
UEQ Perspicuity score	2.2 ± 0.8	2.0 ± 1.0	0.48
UEQ Efficiency score	1.9 ± 0.8	1.9 ± 0.8	0.75
UEQ Dependability score	1.7 ± 1.1	2.0 ± 0.6	0.32
UEQ Stimulation score	2.0 ± 0.7	2.0 ± 0.7	0.80
UEQ Novelty score	2.2 ± 0.6	2.1 ± 0.8	0.78

associated with age ($r = -0.72$, $p = 0.04$) and educational level ($r = -0.72$, $p = 0.04$).

The PSSUQ results in Table II also reveal a positive perception of the application usability and ease of use ($p = 0.0001$), regardless of the user interface adopted ($p = 0.007$). In fact, testers of the two groups indicated the same best aspects of the application, i.e., the information present on the screen to help them perform the measurements and the move from one screen of the application to the other. The significant differences across the categories were only for scores assigned to the TV-based system ($p = 0.0004$). Actually, in this case, the worst score was marked for "System Usefulness", but a relatively high score was also marked for the same aspect in the tablet group, and the difference between the two groups was not statistically significant. This was clearly related to the fact that many of the interviewed older adults did not feel the need to constantly monitor their health status, and no physician supervision was provided by the system.

Furthermore, the tablet-based version of the system marked a worse score for "Interface quality" compared with the TV-based version, which is in line with the expected behavior, even though the difference is not statistically significant.

In the medium-term trial, whose results are presented in Table III, an analysis over time revealed that there was no significant change in the SUS scores, and only a slight improvement. The UEQ results confirmed the positive impression of the respondents concerning the TV-based application. The system achieved very good results in each of the six aspects analyzed in both assessments (at T_1 and T_2). The variation of the reported user experience over time was not statistically significant ($p > 0.05$). The novelty, attractiveness, and perspicuity aspects scored best. For the majority of participants, the application usage and familiarity building was easy because of its features and modules. No statistically significant correlation between the medium-term results and the age, gender, education, drug assumption, and diseases was found. This suggests that after using the device for a period of time, which is associated with the learning period, all these aspects no longer influence the opinion of the user on the system usability. Remarkably, the two scores (SUS and UEQ) stress different aspects, as a statistically significant correlation was found only between perspicuity and SUS score, T_1 (r = -0.68, p = 0.0015).

Figure 7 shows the UEQ results at T_1 and T_2 (the two lines) compared with the UEQ benchmark (the stacked bar plot). From such a comparison, it is possible to conclude that the system, on average, scored "Excellent" on all scales.

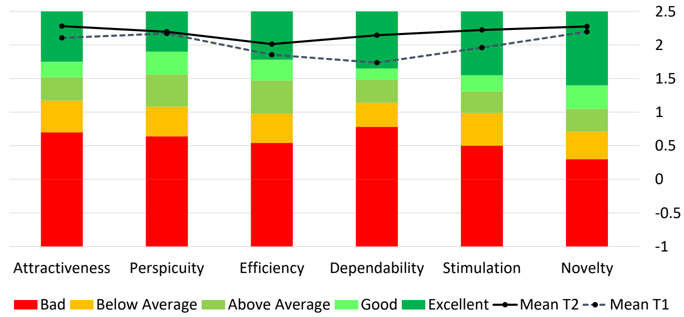

Fig. 7. UEQ results at T_1 and T_2 for the TV-based system, compared with the UEQ benchmark.

TABLE IV
WQ RESULTS (MEAN AND STANDARD DEVIATION) FOR THE CAREGIVERS' PORTAL.

Item category	**WQ score**
Technical adequacy	6.1 ± 0.3
Content quality	6.2 ± 0.2
Specific content	5.8 ± 0.2
Appearance	6.1 ± 0.2

TABLE V
WEBQUAL 4.0 RESULTS (MEAN AND STANDARD DEVIATION) FOR THE CAREGIVERS' PORTAL.

Item category	**WebQual 4.0 score**
Usability	6.09 ± 0.11
Information Quality	6.12 ± 0.19
Service interaction	5.73 ± 0.34
Overall	6.29 ± 0.49

B. Caregivers' portal usability

The results of the caregivers' portal quality, obtained from the WQ questionnaire, are shown in Table IV. All four aspects evaluated marked high scores, the highest one being related to the dimension "Content quality", revealing that the content of the portal is perceived by the respondents as useful, complete, and accurate. The dimension "Specific content" shows the lowest rating, which might reflect some concerns related to finding specific details about the service, customer support, or other information.

In Table V, the results of the WebQual 4.0 questionnaire are shown. The three aspects that were evaluated as well as the overall satisfaction marked high scores. As expected, the results are very similar to those obtained with the WQ questionnaire.

From the semi-structured interviews, it was found that about 70% of the GPs used the ICT systems to manage their patients. Even though all the GPs highlighted that stressful working conditions hampered a continuous monitoring of their patients' physiological parameters, they declared that in their current situation, they would like to use an instrument like the caregivers' portal. The reasons were different, but they mainly mentioned that its use is practical and efficient (70%), conveys useful information (30%), allows a prompt check of the patients (30%), and enables more contact with them (30%). However, they fear that many patients and physicians may not use it often for the latter case because a regular monitoring is often not accomplished by patients (14%) regardless of the adopted device, and that many elderly people would be unable to use the application to collect physiological parameters (30%). Moreover, 30% of the GPs added that continuous monitoring of physiological parameters is not always required, unless a specific health condition is present, whereas the remaining 70% suggested daily monitoring for the elderly. From this viewpoint, 57% of the GPs suggested to add more physiological parameters and inform the patients of the usefulness of the system. Because of the system usefulness, all the GPs declared that this system should be freely given to the elderly by the National Health System, and that the GP is the main person to use the system, even though other specialists (43%) and informal caregivers (14%) could also find it useful.

V. Related work

Several ICT services for the elderly have been experimented in various fields, especially for the elderly living alone and for the management of people with dementia [34], where the most important aspect is the safety and support of the patients in their daily living [35]. Telemonitoring and telecare programs have been developed using different standalone devices (medical devices that send data directly to a server) and services (telephone calls and videoconferencing systems) [36] by relying on home-based technologies and fixed equipment (i.e. computers and smart TVs) [37], [38] or adopting wireless mobile devices, thereby supporting the mobility of patients [39], [40]. Common key health indicators captured by these systems include blood glucose, blood pressure and oxygenation levels, heart rate and weight, and sleep and activity patterns. Moreover, alarms based on the monitoring of specific conditions could be included, exploiting distributed sensing, cyber-physical systems [41], [42], [12] and Internet of things [43] concepts, applied to healthcare. For instance, fall-detection systems [44], including those expressly designed for the elderly at home [45] could be easily integrated in the HEREiAM platform. Other tools such as those for geofencing, used to monitor and intervene on the wandering behaviors of subjects with dementia [46] are in general standalone. Their integration with the proposed system could be performed by taking advantage of the portability of the proposed framework on mobile platforms for m-health scenarios [47], [48].

The success of these systems strongly depends on the willingness of the user to use them, and technology anxiety can represent a factor that reduces the perceived reliability and consequently the use, especially for people with physical restrictions. Designing the interfaces so that they are easy to learn and use [49] could help in overcoming the digital divide. In this sense, specific technologies have been proposed so far, resorting to digital pens [50] or simple videoconferencing systems for telenursing [51]. Conversely, other tools based on the use of a computer and non-specifically developed interfaces could represent an obstacle to the adoption by the users who are sometimes concerned about working with such equipment [52].

In this regard, the choice of a TV as the user interface is an interesting approach, combining advanced features to ease of use. This approach does not represent a novelty in the field, but its method of implementation does. In [53], a DVB-T set-top-box with Multimedia Home Platform (MHP) interface is connected through a USB-to-WiFi adapter to certified medical devices. The idea of using the TV is specifically targeted for older adults with low computer literacy, but compared with the present work, the self-managed health monitoring is the only supported service. Such work exploits the same approach as other previous works in the field [54], [59], but implements a SOA approach to separate interfaces from their implementations, as in the current work. Remarkably, MHP [60] is a standard that is being replaced in all European countries by the new Hybrid Broadcast Broadband TV (HbbTV). In addition, because of the limited diffusion of this more recent standard, the idea to exploit Android as the reference framework in this work does not only allow portability to mobile platforms but also allows the exploitation of Android TV boxes in any country worldwide. A similar choice was followed by [16], wherein Google TV (now Android TV) was adopted to create the iTVCare. Compared with the proposed solution, the above system presents limited functionalities, because it provides support only for medical appointments and medication reminders. A more complete system was recently presented to support social and health services through the use of a media center that supports interactive TV applications (KODI, http://kodi.tv) [55]. Compared with the proposed solution, this above system limits the portability of the framework to support mobile platforms, and some solutions are specific of the used platform (such as the messengers); furthermore, despite the privacy issues associated with the management of health data from the user, SOA approaches and the best practices for exchanging medical data were not adopted. Moreover, in terms of evaluation, no standard assessment tool was used; thus, it was difficult to compare the existing solution [55] with the proposed solution, even though the TV-based approach received the usual good acceptance by the testers.

The adoption of TV apps is common to other studies involving elderlies, even though with different purposes such as the management of elderlies to decrease food insecurity [56]. Although completely different from an architectural perspective, the system presented in [57] was also TV-based and exploited a precommercial prototype, which was able to bridge a TV screen with a mobile phone or computer to support pictures, videos, and text messages streaming toward the TV. The device also provided other services such as games,

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TABLE VI
RELATED WORKS COMPARISON TABLE.

	Targeted for the elderly	Targeted for healthy elderly too	Vital parameters monitoring	Home / environmental sensors	Social and health services	Multiple UIs support	Coherent UI layout design	SOA	Support of medical standards	Validated usability tests
This work	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
[16]	✓	✓	-	✓	-	-	✓	-	-	✓
[35]	-	-	-	✓	✓	-	-	-	-	✓
[36]	-	-	✓	-	-	-	N.A.	-	✓	N.A.
[38]	-	-	✓	-	-	-	-	-	✓	N.A.
[39]	✓	✓	✓	-	-	✓	✓	-	N.A.	-
[40]	-	-	✓	-	-	-	N.A.	-	-	-
[45]	✓	N.A.	-	✓	N.A.	N.A.	N.A.	-	N.A.	N.A.
[50]	-	-	-	-	-	N.A.	N.A.	-	-	-
[51]	✓	✓	-	-	-	-	N.A.	-	-	-
[52]	✓	-	✓	-	-	-	N.A.	-	-	-
[53]	✓	-	✓	-	-	-	N.A.	✓	-	-
[54]	✓	-	✓	-	-	-	N.A.	-	-	-
[55]	✓	✓	✓	-	✓	-	✓	✓	-	-
[56]	✓	✓	-	-	-	-	N.A.	-	N.A.	-
[57]	✓	✓	-	-	✓	-	✓	-	-	-
[58]	✓	-	✓	✓	✓	-	N.A.	N.A.	-	N.A.

N.A. = Not Applicable to the system.

workout suggestions, and communication with the staff or other subjects, expressly created for the device. However, the system cannot gather vital signs or monitor workout; hence, it is limited from the e-health perspective, despite the original aim of the research.

Other projects, such as the elDeRly-friEndly Alarm handling and MonitorING (DREAMING) [58], bring together a set of services, which when packaged together, improve the independence of elderly people. Compared with the proposed system, DREAMING is also based on a set-top-box PC connected to the TV and controlled through an IR remote control. However, the PC is Windows/Linux-based; thus, it lacks the portability of mobile platforms. Furthermore, the PC is only used for videoconferencing services, whereas the health monitoring subsystem, controlling the self-operated medical devices via wireless communication, exploits a different local concentrator connected to the Internet; thus, it has reduced integration levels. In addition, beyond providing a very interesting telecare platform, the adoption of a TV-based system also enables studies on the TV usage patterns and habits [61] with completely unobtrusive solutions; therefore, early signs of health and cognitive deterioration can be identified.

In general, it is difficult to find quantitative results on the assessment of these technologies in the literature, or several pitfalls could have been identified. For instance, recent systematic reviews about remote patient monitoring (e.g. [62]) reveal how despite ICT-supported remote care is proposed in several researches, only 10% of the studies recruited seniors older than 65 years. However, this target population presents peculiarities making the design of telecare systems for their use critical for acceptance. The approach to the assessment followed in this work exploits a representative sample of the expected users, which allows for better identification of the proposed technology's virtues and vices.

In Table VI, a comparison between the main strengths of the proposed platform and related works analyzed in this section is shown. As it can be seen, almost all the related works use only one possible user interface, limiting their usage to an instrumented setting or to a restricted group of people. Regarding the systems specifically designed for the elderly, many of them offer health-related services only, by focusing on people with chronic diseases or pathological conditions. Only a few of them also target active elderly that may only need to monitor their health status with the support of GPs or informal caregivers, or just to access a range of social/participation services otherwise unavailable. Another aspect to evaluate is the coherence of UI layout design when navigating the system interface. In fact, some related works use different layouts for different services or even between screens related to the same service: this could confuse elderly people using their system. A very important aspect analyzed in Table VI is the adoption of medical standards to send and save data, in order to integrate them in EHRs and make them available in a standardized way. Very few related works support such standards. Finally, the methods used to assess the systems usability were analyzed, revealing how only two related works declared the adoption of validated tests and questionnaires. This hampers a point performance comparison.

VI. CONCLUSION

This paper presents the health telemonitoring subsystem of the HEREiAM telecare system, which is based on Android and uses a tablet or a TV as the user interface, and its field-trial evaluation. The cloud infrastructure dictates the main principles to be followed by the Health app to ensure that the system is ready for the market. The result is a solid structure that includes special features designed to enable further developments, such as a ServiceProxy, to improve security and relieve the app developers from the burden of low-level interfacing with the cloud for the different services.

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The design of the Health app, expressly conceived to achieve a good user experience, was recognized by the elderly. It obtained excellent results with all the adopted scales, both at the first use of the system and after four months of daily usage. The evaluation conducted with GPs confirmed that such an instrument is considered useful and can help the management process of the patients.

The main limitations of this study are the low numbers of enrolled testers and the absence of diseases requiring specific continuous monitoring. For this reason, additional medical devices will be integrated (i.e., pulse oximeter, blood glucose meter), and long-term clinical trials involving anticoagulated patients and patients with type-2 diabetes and coronary heart disease will be organized.

Appendix

The trace for the semi-structured interviews administered to the GPs is presented hereafter. As in any semi-structured interview, small deviations from the trace are allowed.

- **Q1** Do you often use IT to manage your patients?
- **Q2** How many of your older adults' patients are living by themselves?
- **Q3** Do you think it's important to monitor the trends of physiological parameters like blood pressure, glycaemia and body weight in elderly patients? (Never, often, sometimes, if they suffer from specific pathologies)
- **Q4** In an ideal scenario, when work hours are not stressful, do you think you would monitor these data more often?
- **Q5** In your current situation, if you had the possibility to use an instrument like the one shown in the video, would you use it for its purposes? (Briefly explain)
- **Q6** From your point of view, one particularly positive aspect (or more) of this system?
- **Q7** From your point of view, one particularly negative aspect (or more) of this system?
- **Q8** Based on your experience, which professional figure should monitor the patient through such service? The general practitioner or others?
- **Q9** In your opinion, such service should be charged? If yes, how should pay and how much?
- **Q10** Would you improve the patient's side of the system? How?
- **Q11** Would you improve the doctor's side of the system? How?
- **Q12** If an automatic software to analyse the trend of data and to send you and the patient a message (via e-mail, text or app notification) would be available, would you find it useful? Do you think it could increase the adoption rate among physicians?

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