A Healthcare Support System for Assisted Living Facilities: an IoT Solution

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A Healthcare Support System for Assisted Living Facilities: an IoT Solution

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***Abstract*—In the field of Ambient Assisted Living a limited amount of research aims at supporting caregivers that work with people with disabilities in assisted living facilities (ALFs). In fact, research activities on healthcare support systems in AAL mainly focus on improving the quality of life for people in their own homes or supporting nurses and doctors in hospitals. This paper explores and applies the Internet of Things paradigm in the ALFs context. In particular, we present the design, the implementation, and the experimental evaluation of a system capable of supporting the daily activities of healthcare assistants that operate in ALFs for people with physical or cognitive disabilities. The solution combines wearable and mobile technologies to improve assistance requests and anomaly detection. With this healthcare support system, caregivers can be automatically alerted of potentially hazardous situations that happen to the inhabitants while these are out of sight. Furthermore, inhabitants can require assistance instantly and from any point of the facility. We evaluated the system in two ways. We performed a functional test with two professional caregivers, and we deployed the system in an ALF in Italy for 36 hours, collecting the opinions of the involved caregivers and inhabitants.**

Keywords*—Internet of Things; Healthcare support system; Ambient Assisted Living; Wearable devices; Disabilities

I. Introduction

One of the challenges that the healthcare sector has been facing in the last decade is how to ensure full coverage of professional care for those who require special attention (e.g., the elderly, people with disabilities, or patients with chronic conditions), while the associated costs continue to increase. To address this challenge, Ambient Assisted Living (AAL) [1] systems have been researched extensively. AAL is a term used to describe a set of technical systems, infrastructures, and services to support elderly people or people with disabilities in their daily routine. It allows an independent and safe lifestyle via the integration of information technologies within homes and residences. Research in the field of healthcare support systems is mainly focused on addressing two problems: improving the quality of life for people in their own homes, especially the elderly, and supporting nurses and physicians in hospitals. However, less research has been done about systems to support caregivers which assist persons with disabilities within Assisted Living Facilities (ALFs)[1] and on how to design them to be effective. To fill this gap, Aced et al. in [2] presented a series of guidelines for designing systems that could effectively support caregivers in tasks such as monitoring ALF inhabitants and attending to their assistance requests. These design guidelines derive from a literature analysis and from the qualitative analysis of a comprehensive user study carried out in three different Italian ALFs for people with physical and cognitive disabilities. In Italy, these nursing homes are known as Residenze Assistenziali Flessibili (RAF). RAFs are health and social care facilities with the aim of providing hospitality, welfare benefits, and recovery to people in mental or physical conditions of dependency. They ensure adequate living conditions for the inhabitants, appropriate for their dignity, by promoting the maintenance or recovery of their residual capacities and the satisfaction of their relational and social needs. The authors conducted three focus groups with a total of 30 caregivers. They concluded that a healthcare support system should be designed taking into account issues such as portability, ubiquity, unobtrusiveness, and automatic detection of hazardous situations.

This paper aims to apply these guidelines to an effective solution of a healthcare support system. In particular, we present the design, the implementation, and the experimental evaluation of an Internet of Things (IoT) [3] system capable of supporting the daily activities of healthcare assistants that operate in RAFs and compliant with the guidelines set forth in [2]. We chose to adopt the IoT technology because this paradigm is being increasingly recognized: the potential of IoT is used to enhance or at least to enrich healthcare support systems by sensing physiological signals ubiquitously and unobtrusively. As the name suggests, the IoT is the network of physical objects that are supposed to be always connected to the Internet with the aim of sharing services and information with other connected "things." In addition to connecting people, anytime and everywhere, IoT connects humans to smart objects, and puts these objects at the service of humanity. The system presented here involves mobile and wearable technologies to improve the modalities to provide and require assistance. Through it, caregivers can be automatically alerted of potentially hazardous situations that happen to the inhabitants while these are out of sight. Furthermore, inhabitants can require assistance instantly and from any point of the facility.

Our work was divided in several phases. First of all, we extracted the requirements from the study reported in [2] in order to design a system based on the needs of real users. After this, we implemented and tested the solution in laboratory. Finally, we evaluated the system in two ways: a) we performed a functional test with two professional caregivers, and b) we deployed the system in a RAF for 36 hours, collecting objective data as well as the opinions of the involved caregivers

[1]an assisted living facility is a housing facility for people with disabilities. ALFs ensure health, safety, and well-being conditions for people in situation of dependency due to cognitive or physical disabilities. In these facilities, unlike hospitals, there are no full-time nurses nor physicians providing medical treatments.

and inhabitants.

The paper describes all the phases of the project life cycle and is organized as follows. Section II presents some background and relevant studies that illustrate what has been already done in the field of healthcare support systems for ALFs. Besides, this section summarizes daily's routine within RAFs according to the study in [2]. Section III presents the requirements followed in this project, while Sections IV and V show the design and the implementation of the healthcare support system, respectively. Finally, Section VI describes the experimental evaluation of the system, Section VII presents the results of the experimentation, and Section VIII concludes the paper with some considerations and future works.

II. Related work

Most of the healthcare support systems found in the literature (e.g., AMON [4] and CARMA [5]) aim at enabling people with special needs to stay at home and to be monitored remotely by medical staff, rather than being hospitalized with the costs this entails. Many of these systems have been implemented by exploiting intelligent environments [6] and mobile technologies [5]. In most cases the focus is on addressing the different needs of the elderly living in home environments, or on building applications in structured environments, such as hospitals, to support medical staff (as reported in [7] or in [8]). Wearable technologies have also been researched as possible enabling technologies, from their first appearances in systems such as WearNET [9] and AMON [4], to more recent tools which combine wearable and environmental sensing for longterm sleep studies, as in the work presented by Borazio et al. [10]. However, few studies and healthcare applications, aiming at supporting users different than doctors in hospitals or patients in their home, are present in the literature. Among them, papers that describe systems to support healthcare workers in nursing homes, often, are not based on IoT or wearable technologies [11], or aim at supporting specific activities only, such as the system for activity recognition to support nursing documentation realized by Altakouri et al. [12].

In addition to the technologies used to implement a healthcare support system, a limited amount of AAL studies in the healthcare domain focuses on user needs and acceptance, rather than on the capabilities of the system and/or the devices. Among these studies we can include, for example, the list of properties desirable in a commercial healthcare system reported by Bhadoria and Gupta [11]. Mayora et al. [13] present a reflection on non-functional requirements that are key in the development of technological solutions for personal health systems. Such requirements come from patients, since the system is intended to directly support them in the treatment of bipolar disorder. In the work presented in [2], the authors propose a series of guidelines for designing systems that could effectively support the caregivers of an ALF in their work. These guidelines are derived from the results of group interviews with the caregivers of three different Italian RAFs managed by the Cooperativa Sociale P.G. Frassati[2]. The purpose of the focus groups consisted in identifying the needs and concerns that healthcare workers in ALFs have, understanding how they tackle problems and difficulties in their daily work, and how technology can help or support them. The interviews were held in three 90-minutes sessions which involved 30 professional caregivers, 22 female and 8 male, with different years of expertise.

[2]http://www.coopfrassati.com (last visited on November 18, 2015)

The last part of this section summarizes some important information of the previous study, since we used the guidelines reported in [2] as a starting point for our work by. Analyzing the paper we can identify the context in which caregivers work. Two of the structures reported in the paper accommodate people with various degrees of mental disorders, while the third one houses people with motor impairments. Each RAF hosts around ten people, and in each facility assistance is guaranteed 24/7. During the day, two caregivers are present within the RAF; a nurse is present 1 hour per day, every day; while a doctor is available on request, only. During the night, only one caregiver is present in the facility, performing some houseworks and running ward rounds. RAFs generally share some characteristics such as the presence of a backyard, a fully equipped kitchen, a living room and shared bedrooms for the inhabitants. Common needs emerged from the caregivers across the three focus groups, with some minor differences due to the diverse type of disabilities. In fact, inhabitants with motor disabilities are less autonomous and independent than inhabitants with mental disabilities who, in most cases, can leave the house and walk around the town without any assistance. However, the inhabitants with mental disorders have to be closely monitored, because they may suffer epileptic seizures, or they may try to break or escape the RAF. Instead, the inhabitants with motor disabilities require assistance in order to perform daily activities that they would not be able to carry out otherwise.

RAF inhabitants can request the assistance of a caregiver by calling her by voice or using buzzers which are in fixed positions around the house. However, there are situations in which caregivers cannot hear the inhabitants, or where the buzzer is not reachable. These missed calls constitute the main problem for the healthcare assistants: at the moment, this is an aspect that they consider not addressed. Furthermore, the use of the current system for assistance, composed of buzzers and light panels, is a source of discomfort: the loud noise produced by an alarm can upset the peacefulness of the facility.

Each caregiver brings with her a cordless phone, multiple keys and, in some cases, her personal smartphone. RAF inhabitants with cognitive disabilities, unlike those with motor impairments, do not own any technological tool, such as smartphones, tablets, or computers. Caregivers and inhabitants' parents promote this situation, because of the possibility that such objects might be stolen, broken or forgotten outside the RAF.

III. Requirements extraction

The first phase of our work consisted in analyzing the results of the focus groups with professional caregivers in order to extract a set of requirements for designing a healthcare support system compliant with the guidelines set forth in [2].

A. Guidelines from previous work

A healthcare support system should be designed taking into account issues such as portability, ubiquity, unobtrusiveness and automatic detection of hazardous situations [2].

One of the most common requests across all focus groups, was the caregivers' need of having the hands empty or free from any objects. In fact, they should be always ready to attend any situation in which an inhabitant is involved. For this reason, the devices used by a healthcare support system should be easily taken around the assisted living facility by the caregivers, without representing a source of discomfort. Furthermore, the system should not introduce unnecessary devices for the inhabitants, because most of them do not actually own any technological tool, such as smartphones or tablets. Finally, all the objects and tools used by the caregivers should be resistant to water and shocks, given the fact that their attention has to be directed to the RAF inhabitants and not to devices integrity.

An important issue that emerged during the focus groups concerns the modalities used by inhabitants to consciously require assistance. Nowadays, they have to call caregivers by voice or using a buzzer that is fixed in some locations inside the environment. However, there are situations where caregivers cannot hear the inhabitants calls, or where the buzzer is not reachable. In fact, inhabitants may be outside the house, away from caregivers (e.g., in the backyard), or they may have fallen out of the wheelchair, unable to use the buzzer. These missed calls are a problem that currently is not tackled, but that caregivers perceive as "really important" since they are not able to timely intervene. For this reason, a healthcare support system should support caregivers and inhabitants regardless of their location inside the facility. Furthermore, the buzzer and its usage are sources of discomfort, in particular for the the loud noise produced to notify a request for help. Thus, the system should offer to the inhabitants a mechanism for requesting caregivers assistance that does not disturb other people within the assisted living facility.

A related problem in RAFs is how to monitor the inhabitants while they are out of sight in order to assist them in time, in case of need. In fact, inhabitants with either mental or physical disabilities may need quick assistance, but may not be able to request it, e.g., they may be in the middle of an epileptic seizure. Until now, the problem has been tackled by running overnight ward rounds to constantly check for potentially hazardous situations, while during the day it has not been tackled at all. Caregivers need a healthcare support system that helps them to monitor the RAF inhabitants when they are out of sight. Such a system should be able to recognize when some hazardous situation is taking place and then notify the caregivers. The accuracy of the detection process is not crucial: according to the caregivers, "false positives" are better that "false negatives."

As reported in the description of daily's routine within a RAF, during the night only one caregiver is present in the facility. The reason is that during the day there are more activities to be carried out and the inhabitants require more attention than during the night, while they are asleep. However, caregivers fear that something bad could happen to themselves and no one could help them while they are alone (without a colleague nearby). Caregivers worry for themselves but also for the RAF inhabitants, because if a hazardous situation occurs, the inhabitants could suddenly remain without anyone to assist them. In the same way that caregivers expressed their desire to have "something" to allow the inhabitants to call them effectively in case of need, a healthcare support system has to provide some mechanisms to support caregivers when they are alone.

B. Requirements

The requirements to design and implement the healthcare support system presented in this paper derive directly from the guidelines reported above, with some additions. Table I reports these requirements, numbered from R1 to R10. They summarize the most important aspects followed to design and implement the system.

The first requirements regard the devices to be used. The system should be designed taking into account issues such as ubiquity and portability (R1 and R2). It is clear that a natural consequence is the use of mobile and wearable technologies. In particular, all the observations extracted from the focus groups can be easily addressed with wearable devices. The robustness of the used devices is another important requirement (R3). The devices should be resistant to water and shocks, as reported in all focus groups.

We defined five requirements to design the modalities for requiring and providing assistance. First of all, the system should allow the inhabitants to require instantly the caregiver assistance (R4). Also, the system should offer an automatic detection process of hazardous situations, at least for what concerns epileptic seizures and falls, two of the most common problems suffered by inhabitants (R5). To satisfy all the guidelines of the previous work, the system should confirm that the assistance requests are addressed properly by at least one caregiver (R6), and the new mechanism for requesting caregiver assistance should not use noising buzzers. In fact, the system should not disturb the peacefulness within the assisted living facility (R7). The last requirement about the assistance mechanism is specific for the caregivers. The system should provide the caregivers with an immediate way to call for help in case of need (R8).

Finally, we established two specific requirements regarding the communication between the devices. First, a general but not less important point concerns reliability (R9). The transmission of a request for help through the system must be reliable, because the ultimate goal of this system is to help caregivers to provide assistance to the inhabitants whenever it is needed. Second, the system requires an Internet connection (R10). In fact, our solution is an IoT system and it uses the Internet as a communication network.

Summarizing, we defined 10 requirements to design a healthcare support system. These requirements concerns issues such as ubiquity (R1), reliability (R9), and portability (R2). We chose to apply the IoT paradigm and use Internet as a communication network (R10). Our goal is to improve the modalities for requiring and providing assistance through a new mechanism (R4, R5, R6, and R7) that involves robust and wearable devices (R3 and R2). In particular, we thought to introduce an anomaly detection process for the inhabitants (R5) and an emergency call option for the caregivers (R8).

TABLE I: Requirements followed in the design of the system.

Number	Requirement	Description
R1	*System ubiquity*	The system should support caregivers through their daily activities, regardless of their location inside the assisted living facility.
R2	*System portability*	The used devices should be easily taken around the assisted living facility by the caregivers and the inhabitants, without representing a source of discomfort.
R3	*Robustness of the devices*	The used devices should be resistant to water and shocks.
R4	*Smart assistance*	Thanks to the system, an inhabitant should be able to instantly require the caregiver assistance.
R5	*Automatic detection*	The system should be able to detect potentially hazardous situations in which the inhabitants may be involved without any explicit request. Caregivers should be alerted without the need of constantly running ward rounds or using privacy invasive methods (e.g., video recording).
R6	*Assistance delivery confirmation*	The system should verify that for each request received from inhabitants of the ALF, the proper assistance is actually provided.
R7	*Unobtrusiveness of the assistance request mechanism*	The system should offer to the inhabitants a mechanism for requesting caregivers assistance that does not disturb other people within the assisted living facility.
R8	*Emergency call option for caregivers*	The system should allow the caregivers an immediate way to call for help in case of necessity.
R9	*Reliability and stability*	The system must be intrinsically safe, reliable, and stable, in particular for what concerns the communication between the devices.
R10	*Internet availability*	The system is an IoT solution and uses the Internet as a communication network.

IV. System design

A. Architecture

The architecture of the system is shown in Figure 1. Each caregiver and inhabitant of the RAF is equipped with a wearable device, which ensures system portability (R2). With these devices the users can use the system regardless of their location inside the RAF (R1). Inhabitants are monitored through their wearable accessory, in particular for what concerns seizures and falls (R5). Furthermore, they may require assistance instantly, from any point of the facility (R4). Caregivers are able to manage the help requests through their wearable devices. In this way, we ensure the unobtrusiveness of the assistance request mechanism (R7).

We chose to adopt smartwatches as wearable devices because they are more accessible than other devices one may carry [14], and, in addition, a wristwatch is ideally located for body sensors [15] and as a wearable display [16]. The information exchanged between the devices are represented through textual messages, in the form of notifications. The solution provides a central server in charge of managing the overall. The central node performs some important operations, such as user management, authentication process and persistence of information. Furthermore, the server manages the communication between the devices. For this reason, none of the smartwatches interact directly with the others. To better understand the communication process, think of an inhabitant who wants to get help: through her smartwatch, she can send a message to the server, which will propagate the information to all registered caregivers.

B. Use cases

The behavior of the system can be described through three use cases:

Fig. 1: System architecture

1) voluntary request of an inhabitant;
2) automatic request of an inhabitant;
3) request of a caregiver.

Through her smartwatch, an inhabitant can voluntary request assistance (use case 1). The same wearable device monitors the conditions of the inhabitant. It triggers an automatic request for help (use case 2) in case of falls or seizures. As shown in Figure 2, a notification is immediately sent to all caregivers on duty, which will display on their smartwatches the type of problem and the involved inhabitant. The system, in particular for what concerns the monitoring of seizures and falls, is not designed to accurately identify potentially hazardous situations, but to detect some anomalous motion patterns. In other words, “false positives” are better than “false negatives” for this solution. Healthcare assistants required this type of behavior, since they prefer having to handle a false alarm than missing one.

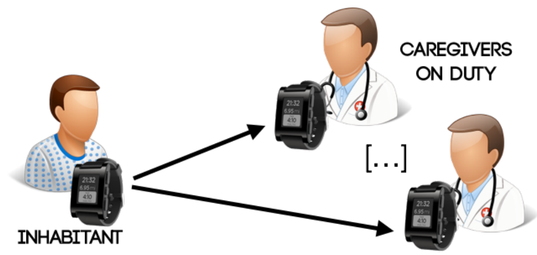

Fig. 2: Use cases 1 and 2

In the last use case (use case 3), caregivers can contact their colleagues in case of need (Figure 3). Through their smartwatches they can send a notification to all other assistants, even those at home. In this case, in order to instantly catch the attention of all assistants, notifications are shown on their smartphones.

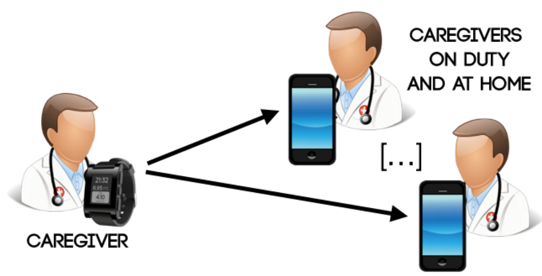

Fig. 3: Use case 3

The system focuses principally on the assistance for inhabitants. In particular, use cases 1 and 2 are composed of three phases:

1) generation of the request;
2) acceptance of the request;
3) termination of the request.

1) Generation of the request: the generation of the request is the first step in the assistance process. In this phase, an inhabitant reaches all the caregivers on duty with a notification (Figure 4).

In detail, if the smartwatch of the inhabitant detects a request for help (thanks to the monitoring, or after a voluntary request), it generates an alarm and sends it to the server as a textual message. The server interprets the received message and propagates the information to the caregivers on duty. The smartwatch will periodically resend the alarm until the request is terminated.

2) Acceptance of the request: the acceptance of the request is the second phase of the assistance process. Thanks to the generation of the request, all caregivers on duty are informed of the danger situation. In this phase, at least one caregiver should take charge of the request through her smartwatch (Figure 5). In this manner, all other healthcare assistants are informed that someone is taking care of the inhabitant.

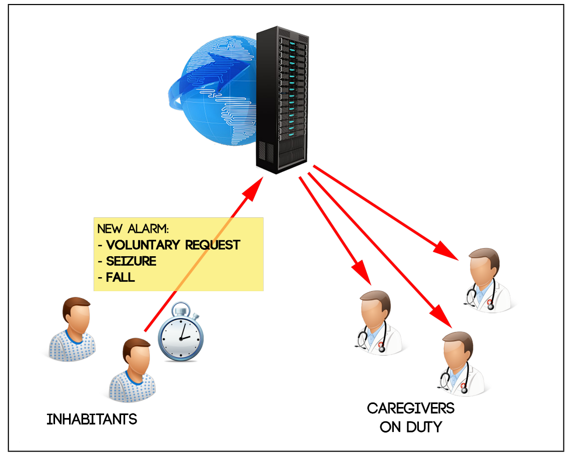

Fig. 4: Generation of the request

Specifically, the smartwatch of the caregiver that performs the acceptance of the request sends an acceptance notification to the server, which will propagate the information to all other assistants on duty. The server turns off the propagation of the request alarm temporarily. However, it checks that the termination of the request is carried out, otherwise it resumes the alarm signaling.

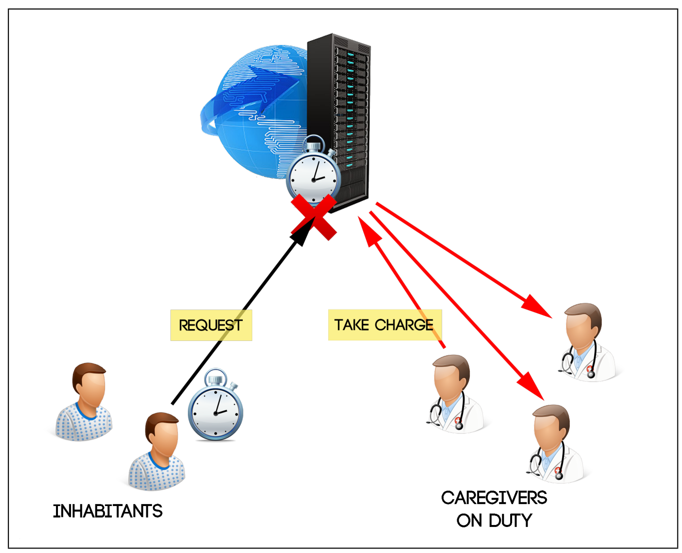

Fig. 5: Acceptance of the request

3) Termination of the request: the last phase of the assistance process is the termination of the request (Figure 6). With this phase, a caregiver can stop the alarm signaling and close the request.

To terminate the ongoing alarm, the caregiver who has accepted the request has to press a button on the inhabitant’s smartwatch. In this way, the system ensures that the proper assistance is actually provided. The system provides a proximity check to prevent accidental pressing and to ensure that the request of termination came from the caregiver. If the assistant is sufficiently close to the inhabitant, the smartwatch of the inhabitant sends the notification of termination to the server, and stops to periodically resend the alarm. The cycle of the request for assistance is finished.

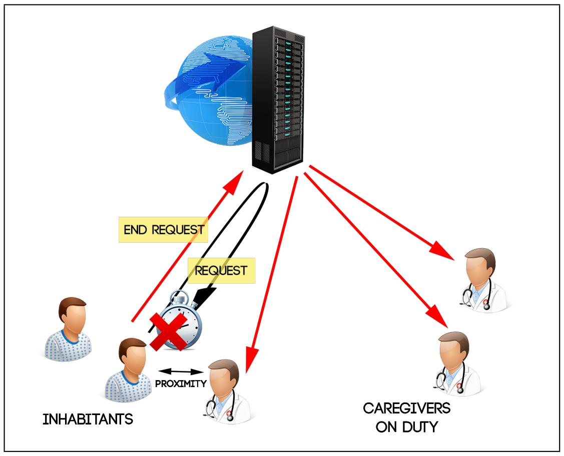

Fig. 6: Termination of the request

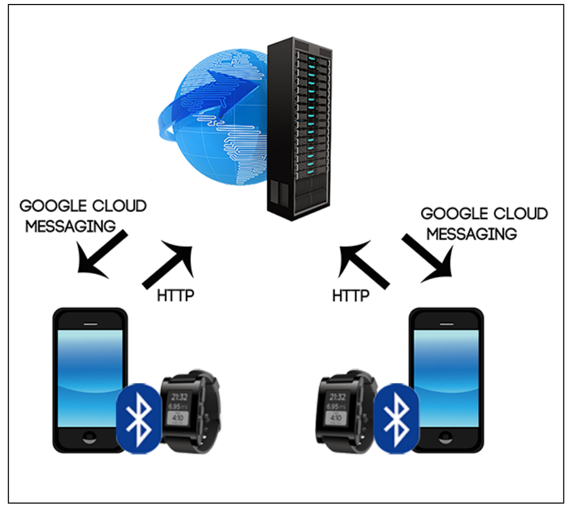

Fig. 7: The communication between devices

V. System implementation

The system can be divided into two main areas: users' devices and central server. For what concerns the wearable devices for the inhabitants and caregivers, the designed system has been realized with Pebble[3] smartwatches. Unfortunately, these types of devices do not provide a way to directly connect to the Internet, but they need an associated smartphone or tablet to do that. We chose to use Android smartphones to perform this operation.

As shown in Figure 7, the elements of the system communicate with each other in several ways. A smartwatch is paired with its mobile device via Bluetooth. Mobile devices can reach the server through HTTP requests, while the same server can contact the clients asynchronously with the Google Cloud Messaging (GCM) service[4].

Search for devices in the "termination of a request" case is performed via Bluetooth Low Energy.

A. Devices for users

We implemented four applications for users: two Pebble applications, one for caregivers and one for inhabitants, and the two paired Android apps. The Android applications for caregivers and inhabitants are quite similar. These applications are designed to be invisible for the user: they mainly work in background, except for the initial authentication. They intercept messages and allow the communication, acting as intermediaries between the paired smartwatch and the server. Furthermore, they allow the Bluetooth Low Energy proximity check to ensure that the termination of an alarm is performed by a caregiver, only. To do that, the mobile device of a caregiver acts like a beacon to be discoverable from the mobile device of an inhabitant.

The implemented Pebble application for the inhabitant's smartwatch enables the voluntary request and performs the monitoring of epileptic seizures and falls in background. In this way, also a user that is not able to directly interact with the device can benefit from the system. The anomaly detection process is done through the on board accelerometer. The application continuously collects, processes, and analyzes accelerometer data in order to detect seizures and falls. Considering that the accuracy of the detection process is not crucial, we chose a simple algorithm based on some thresholds (e.g., acceleration peaks and acceleration average). In this way, the monitoring can be done directly on the smartwatches, which have low computational capacity. Thus, no accelerometer data are transferred between the devices, and the Bluetooth communication between the smartwatch and the paired device is not burdened with too many messages. The two main screens of the application are shown in Figure 8. In the first image, the barred bell indicates that the user has no ongoing requests, so his state is safe. For example, the user can consciously request assistance by pressing the center button of the smartwatch, as shown by the action bar menu. The second image indicates that the user is requesting help. To turn off the alarm, a caregiver must press the up button of the smartwatch.

(a) *The application when the state of the inhabitant is safe*

(b) *The application when the inhabitant is requesting help*

Fig. 8: The Pebble application for the inhabitant

The application for the caregiver's Pebble presents a richer user interface. It is designed through a series of menus to allow the assistants to provide assistance. Caregivers can view the ongoing alarms, communicate to their colleagues the availability to serve a request, and view all the alarms that they

[3]http://getpebble.com (last visited on December 3,2015)

[4]https://developers.google.com/cloud-messaging/ (last visited on December 3,2015)

have taken under their control. From the same application a caregiver can send a request for help to her colleagues. Some screenshots of the application are shown in Figure 9.

(a) *The menu screen* (b) *The ongoing alarms menu* (c) *A message shown to the caregiver*

Fig. 9: The Pebble application for the caregiver

B. *Central server*

We implemented the central server as a Java Enterprise Edition web application. All the application has been developed through the Model View Controller (MVC) pattern, which ensures modular and reusable code. The main part of the server is a RESTful web service which allows the communication between the devices. All smartphones contact the server through an HTTP request to communicate something to other devices. In agreement with the REST architecture, considering the type of the request and the URL, the server maps the request on a specific entity (or collection of entities) that describes the system environment. The web application acts on the model, applies the application logic, and produces a response for the client. Eventually, it can send an asynchronous message to other users through the GCM service.

In addition, the web application offers a web site that caregivers can use to administer the system. Through it, they can manage user accounts and view the history of all the alarms generated in the facility. Following the MVC pattern, the web site is the view of the server application. A screenshot of the home page is shown in Fig 10.

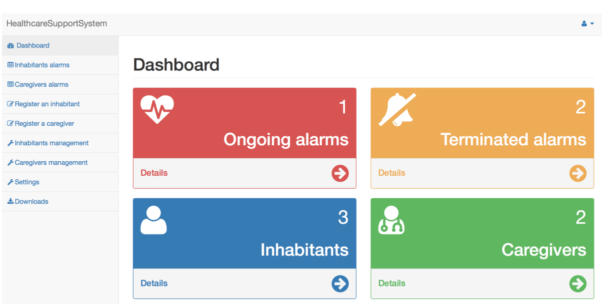

Fig. 10: The web site for the system administration

VI. Experimental evaluation

The experimental evaluation of the proposed system was performed along two directions. First, after some in-lab tests, we assessed the user acceptance and the perceived usefulness of the system with a functional test. In this phase, we tried the system with a group of healthcare assistants working in a RAF in Turin. Second, we performed an operational test. We deployed the solution in a RAF near Turin for 36 hours, collecting objective data as well as the opinions of the involved caregivers and inhabitants. Both tests were held in Italian, the native language of participants.

A. *Functional test*

For measuring the user acceptance of the system we performed a functional test with two caregivers working in one Italian RAF. This facility, called “Officina delle Idee”[5], is managed by the municipality of Turin and hosts six people with physical disabilities, only. It employs two caregivers during the day, and one healthcare assistant during the night, similarly to the RAFs involved in the focus groups reported in [2].

Before the test, we distributed an initial questionnaire to the caregivers. We collected some information about their age, their experience in the field of healthcare assistance and their knowledge of technological devices. The participants were two professional caregivers more than 50 years old, each with more than 10 years of healthcare experience. Only one caregiver was familiar with mobile devices and PCs. Furthermore, both were not familiar with wearable devices.

The functional test of the system consisted in simulating some common scenarios, where the two volunteers acted like a caregiver and a RAF inhabitant, equipped with one Pebble smartwatch each. We simulated a voluntary request of the inhabitant, with all the operations required for its termination. We also tested the monitoring of hazardous situations. In this case, the volunteer acting as the inhabitant moved his arm in such a way that the smartwatch detected an epileptic seizure. After the test, we gave a final questionnaire to the participants, in order to collect their opinions about the system, whose results are summarized in Section VII.

B. *Operational test*

The last and more important experimental evaluation consisted on the deployment of the system in one RAF for people with cognitive disabilities managed by the Cooperativa Frassati for 36 hours. The aim of this test with real users was to demonstrate the usefulness of the system, both for caregivers and inhabitants.

We repeated an extended version of the functional test reported above with a group of four professional caregivers and three educators, as training for using the system. Table II and Table III summarize the profiles of the participants and their experience with mobile and wearable devices, respectively. In this phase, four volunteers acted like two caregivers and two RAF inhabitants, respectively, while the rest of the group looked at the test. In addition to the operations for requesting and providing assistance, we introduced them to the administration web site. The training session was audio recorded for further analysis.

After the training phase, we equipped two inhabitants of the facility with a Pebble smartwatch and an associated smartphone, leaving the system running for 36 hours. In this

[5]http://www.comune.torino.it/servizisociali/vigilanza/presidi/disabili/ss_officina.pdf (last visited on December 11, 2015)

TABLE II: User profiles

(a) *Age*

Age	Count
16-25	0
26-35	2
36-45	3
46-55	2
55+	0

(b) *Expertise*

Years of expertise	Count
1<	0
1-2	1
2-5	0
5-10	3
10+	3

TABLE III: Experience with technological devices, assessed on a Likert scale

(a) *Mobile devices*

Experience	Count
1 None	1
2 Little	3
3 Sufficient	2
4 Good	1
5 Excellent	0

(b) *Wearable devices*

Experience	Count
1 None	4
2 Little	2
3 Sufficient	1
4 Good	0
5 Excellent	0

way, we covered three day shifts and one night shift, involving six caregivers. During the evaluation, we collected data about the usage of the system. Finally, we distributed a final survey to the involved caregivers and inhabitants, whose results are summarized in Section VII.

VII. RESULTS

From the experimental evaluation of the system we extracted two levels of results, thanks to the functional test and the operational test.

A. *Results of the functional test*

We extracted the first results about the user acceptance and the perceived usefulness of the system thanks to the functional test.

During the test, we observed the actions of the caregivers. We noticed that, after a first approach with the system, the participants performed the required operations without any difficulty.

After the test, the participants expressed their first impressions in a brief discussion. They confirmed that the system might be useful, in particular for large facilities. However, they expressed the need of having a voice recognition feature in addition to the current methods for requiring assistance. In fact, the inhabitants of the facility are not able to use their hands to request assistance consciously, because they suffer from severe physical disabilities.

With the final questionnaire we collected the opinion of the participants quantitatively. Questions were based on a Likert scale with five responses ranging from “Not at all” (1) to “Very much” (5). Both caregivers confirmed the usefulness of the system. They said that the system could improve their work and they expressed their satisfaction for the system portability, the intuitiveness of the user interfaces, and the system usability. The results of the caregiver answers are summarized in Table IV.

TABLE IV: Results of the functional test

Question argument	Average	SD
System usefulness	4.00	0.00
System intuitivenness	4.00	1.00
System usability	3.50	0.50
System portability	4.00	1.00
Positive influence on daily work	4.00	1.00

B. *Result of the operational test*

The operational test was the last and more important part of the experimental evaluation. We repeated the functional test as training for using the system. We noticed that also in this facility, after some indications, the involved caregivers didn’t have any difficulty to learn how to use the system. Considering that the same behavior was observed in the previous functional test, we may conclude that the system learning process is very fast.

After the training of the system, the caregivers chose two RAF’s inhabitants in order to try the system for 36 hours. This operational test covered three day shifts and one night shift, involving six caregivers. Unfortunately, the inhabitants used the system sparingly. For this reason, we can’t draw any consideration from the generated data.

The final questionnaire, an extended version of the one used for the functional test, gave us more results. On a Likert scale with five responses ranging from “Not at all” (1) to “Very much” (5), the involved caregivers evaluated the system usefulness, usability and portability. Furthermore, they gave an opinion about the intuitiveness of the user interfaces and about the possible influence of the system in their work. The results of this analysis are summarized in Table V.

TABLE V: Results of the operational test

Question argument	Average	SD
System usefulness	3.33	0.53
System intuitivenness	3.00	0.63
System usability	2.67	0.52
System portability	2.83	1.31
Positive influence on daily work	3.67	0.82

In addition, three caregivers said that the modalities by which an inhabitant can request assistance are sufficient, while the other three would like more possibilities. Besides, three assistants were satisfied of the system features for providing assistance, while three confessed that they were not entirely satisfied.

The questionnaires compiled by the two inhabitants confirmed their limited use of the system. The only relevant obtainable information is that an inhabitant would like a less complex wearable device, like a bracelet with a single button.

C. Discussion

We extracted positive results from all the tests and we demonstrated the system stability and reliability. All involved caregivers confirmed the usefulness of the system. In particular, they said that the system could improve the work in RAFs. The experimental evaluation was also useful to identify possible improvements, in particular for what concerns the system portability and usability. Unfortunately, the operational test involved only two inhabitants, which used the system sparingly. For drawing more specific conclusions we are planning to repeat the test with all caregivers and inhabitants of at least one RAF.

VIII. Conclusions

In this paper, we presented an IoT system capable of improving assistance requests and anomaly detection in an ALF through wearable devices. With this healthcare support system, caregivers can be automatically alerted of potentially hazardous situations that happen to the inhabitants while these are out of sight. Furthermore, inhabitants can require assistance instantly and from any point of the facility. Requirements for building such a system were extracted from a previous study [2], in which the authors conducted a series of focus groups with professional caregivers. The design of the system focused principally on portability and ubiquity. The system was implemented and tested in two phases. First, we performed a functional test with two professional caregivers to verify the user acceptance and the perceived usefulness. Second, we deployed the system in a RAF for 36 hours, collecting the opinions of the involved caregivers and inhabitants.

Future work will concern the increase of the possibilities to request assistance for inhabitants. In fact, people with severe physical disabilities hardly interact with wearable and mobile devices. In parallel, we are planning to generalize the solution to other devices, thinking at the progress of wearable devices. Without the need of having a paired mobile device to connect to the Internet, the system portability can be improved. Finally, we are planning to repeat the operational test with more caregivers and inhabitants.

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