IoT garment for remote elderly care network

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A B S T R A C T

The elderly is a continuous growth sector thanks to the life expectancy increase in Western society. This sector is especially at risk from the appearance of respiratory diseases and, therefore, is the most affected sector in the COVID-19 epidemic. Many of these elderly require continuous care in residences or by specialized caregivers, but these personal contacts put this sector at risk. In this work, an IoT system for elderly remote monitoring is studied, designed, developed and tested. This system is composed by a smart garment that records information from various physiological sensors in order to detect falls, sudden changes in body temperature, heart problems and heat stroke; This information is sent to a cloud server through a gateway located in the patient's residence, allowing to real-time monitor remotely patient's activity using a customized App, as well as receiving alerts in dangerous situations. This system has been tested with professional caregivers, obtaining usability and functionality surveys; and, in addition, a detailed power-consumption study has been carried out. The results, compared with other similar systems, demonstrate that the proposed one is useful, usable, works in real time and has a decent power consumption that allows the patient to carry it during all day without charging the battery.

1. Introduction

The number of dependent people who need to be monitored continuously increases every day. This fact has becomes more important with the appearance of the COVID-19 pandemic [1]. Several countries (like Spanish government) decreed a state of alarm that forced population to spend several months in their homes. However, one exception to this emergency state was precisely going to visit elderly or dependent people's home to monitor their health situation and to provide the help they might need.

People who can do these tasks were both family members and caregivers. Although this activity was legally allowed, it became dangerous, since the elderly is precisely the most vulnerable sector in this pandemic. So, because of those physical contacts, the infection possibility increases; even more if the familiar or caregiver carries the virus asymptomatically [2]. Additionally, it should be noted that the possibility of contagion by contact is not only applicable to the SARS-Cov-2 virus, but is also one of the main factors that spread other epidemics, such as flu, which seriously affects the elderly population as well.

Several tasks have been adapted to this new normality and those physical contacts have decreased. But there are some physical visits that need to continue, like controlling insulin level in diabetics patients or monitoring other health alerts (falls, heart beats, blood pressure, etc.). Moreover, the main issue surrounding these measurements is that they are controlled during the caregiver visit only; but, if there is a dangerous situation when the patient is alone, it may cause irreversible health problems.

So, an integrated system that allows monitoring the main vital signs of the patient remotely would allow caregivers or family members to have these people under control and check that there are no abnormalities. This solution may have two consequences: the continuous monitoring would allow to detect possible anomalies that would not be detected in a normal visit; and, apart from that, the periodic caregivers' visits can be reduced, so the infection probability decreases.

Although these actions are actually justified by the pandemic, this problem will continue to be important in the coming years: according to the latests CSIC (Spanish Superior Council of Scientific Investigations) reports [3], in Spain there are more than 8 million people over 65 years (a 17% of the 46.94 million population actually), and this sector will

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double in just 20 years (when the largest population sector actually reaches 65 years old), This can be seen in Fig. 1, where can be observed that there are fewer young people and more older people so, in a near future, the number of caregivers will be overwhelmed by the number of dependent people.

Apart from COVID-19 situation and the increase in the elderly population, the economic and timing aspects appear too. In Spain, according to the Ministry of Labor and Social Affairs, the global cost derived from elderly care in 2013 was barely 3% of the Gross domestic product (GDP), but in 2020 it will be higher than 6%; and this amount increases year by year, reaching about 5,800 million euros in 10 years only in Spain [4].

Moreover, the professional caregivers' work journey often varies, as they do not know when they are going to arrive or leave each place, usually spending more hours than necessary in people's houses that they are taking care of. According to some studies [5], only 12% of professional caregivers do not see their lives affected at all by their works or are affected very slightly. The study divided people into 9 different levels (as shown in Fig. 2) where level 1 indicates that it does not affect her life at all, and level 9 indicates that it completely affects her life, having to reorganize his/her life to adapt it to the elderly care. Fig. 2 shows that almost 90% of the caregivers cannot lead a normal daily life due to the restrictions of their work and, as can be seen, only 10% of them suffers very few alterations in their lives.

So, in order to solve these problems and improve patients care, multiple studies have used techniques derived from IoT (Internet of Things) in order to remotely monitor the activity of those patients. First, it is important to show the classic e-health systems, that are detailed in Table 1 and that are based on the review done in [6].

As can be observed, the three main systems are Tele-care, Tele-monitoring and Telemedicine. Actual and particular solutions like "Smart Home" (integrating home automation aspects to avoid several rutine activities to be done) and virtual assistants are different evolutions of Tele-care systems [7–10]. And other solutions like wearable systems (or "Smart Clothing") are Tele-monitoring evolutions [11–13]. All of them have been the result of the application of IoT and telecommunication technologies to the classical e-health systems.

So, many forms of IoT systems can be used to address the needs of elderly healthcare. The most popular system actually is "Smart Home", as it helps the user to avoid repetitive activities. On the other hand, tele-monitoring systems are more difficult to be found, as they do not have a direct benefit to the user itself; but they are very useful to caregivers and family, in order to detect abnormal situations [14,15]. Some works done about wearable systems inside tele-monitoring are [16–18], but they only detect a concrete abnormal situation.

That is why, in the COVID-19 era, we need to detect some particular medical situations like dangerous heart rate variations, sweating, skin temperature, falls, etc. Using "smart home" solutions, falls can be detected, but the other health problems need more specific and physiological sensors; so our system must be situated inside the tele-monitoring systems and, more precisely, as a "smart clothing" system. Some works have developed new and cheap techniques to detect that disease [19], but in the meanwhile it is important to reduce physical contact with population at risk.

So, taking into account the previous introduction, in this work we design, implement and evaluate a remote elderly monitoring system based on a wearable device placed in the clothes. As detailed by Albahri et al. [20], tele-monitoring is effective in chronic disease management of elderly patients as well as efficient lowering mortality rates and hospitalization [21]. So, we aim to monitor the elderly status in real time to detect any problem or pathology as soon as possible and thus avoid the problems that may cause. Likewise, this would reduce the caregivers mobility, reducing the risk of contagion of COVID-19 which, in the situation in which we are, is an important point to take into account.

The novelty of this work resides on the integration of several physiological sensors in a low-power wearable t-shirt capable of transmit physiological information and alert about anomalous situations like dangerous heart rate variations, sweating increase, dangerous skin temperature variations and falls.

The rest of the manuscript is organized as follows: first, in the 'Materials and Methods' section, the wearable system and the alert system
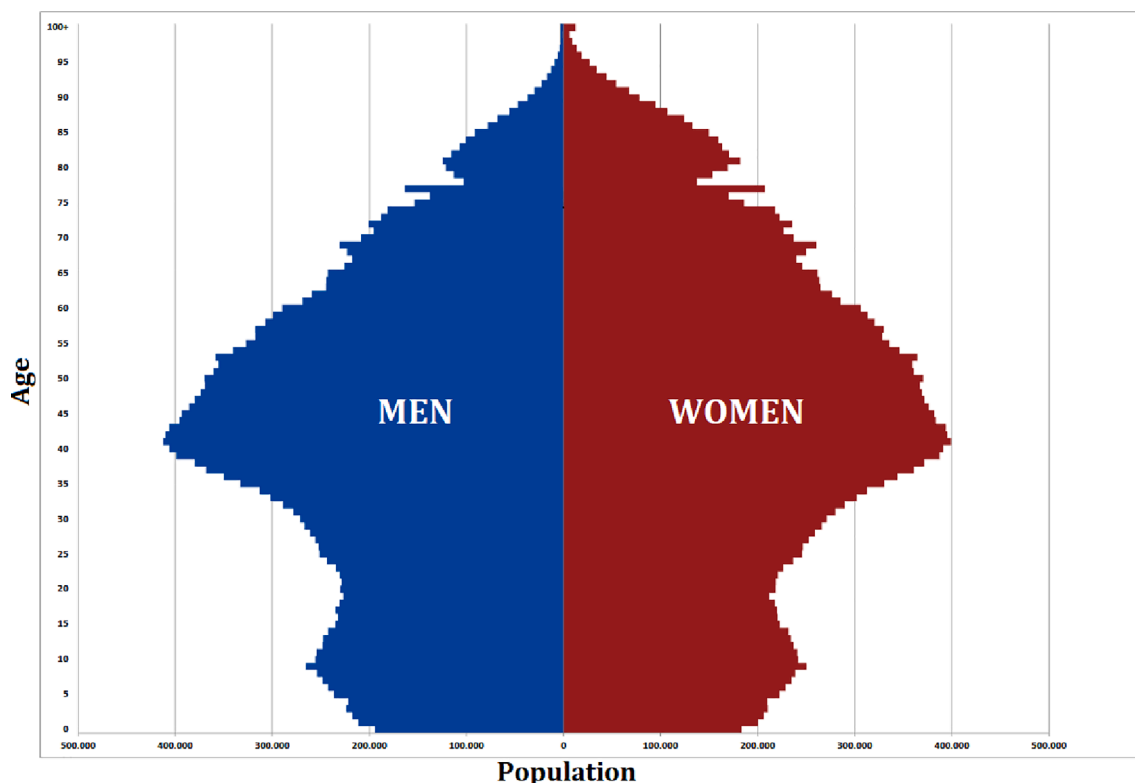

Fig. 1. Spanish Population (information taken from Spanish National Statistics Institute).
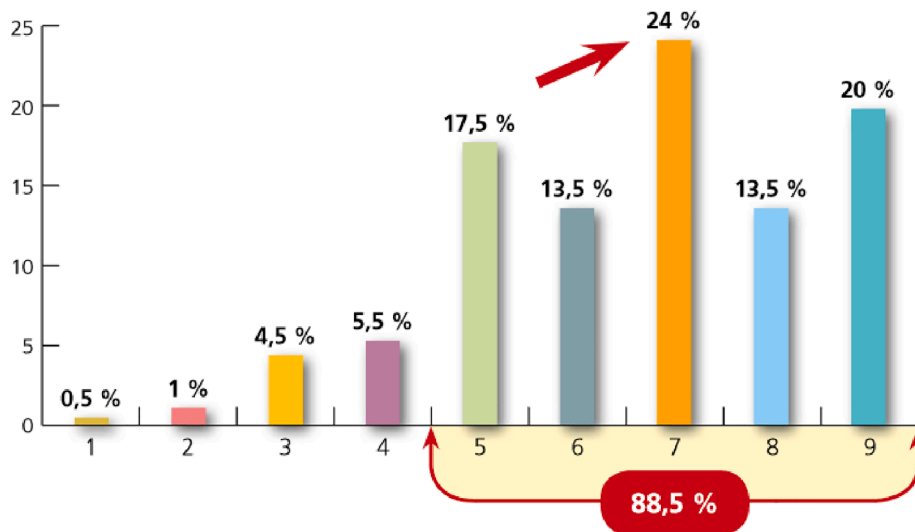
Fig. 2. Survey carried out to professional caregivers about the impact of their work on daily life.

Table 1
Systems types commonly used for remote monitoring and healthcare.

System type	Definition	Scope
Tele-care	Monitoring and providing assistance in the home environment	Help user with daily activities
Tele-monitoring	Monitoring and alert about anomalous situations	Help caregivers and family with patient status
Telemedicine	Monitoring and providing medical treatment	Help doctors with patient health status

are detailed, as well as the procedure for evaluating the full system. Next, in the 'Results and Discussion' section, the evaluation and usability results are detailed. Finally, conclusions are presented.

2. Materials and methods

This section will be divided in two main sections. On the one hand, we will present the full system implementation: the wearable system developed (both its hardware and software), its cloud connection and the alerts notifications. On the other hand, we will detail the tests and metrics used to evaluate the operation of this system.

2.1. Elderly care IoT system

The full system developed for this work consists in four main components: the wearable device (t-shirt), the connection gateway used to transmit the information, the cloud service that communicate the user with the caregivers, and the notification app used by the caregivers. A preliminary vision of the full system is shown in Fig. 3.

In order to evaluate the power consumption of the system, two main solutions for the connection gateway were developed: in the first one, a fixed connection device (based on a Raspberry Pi computer) is placed in
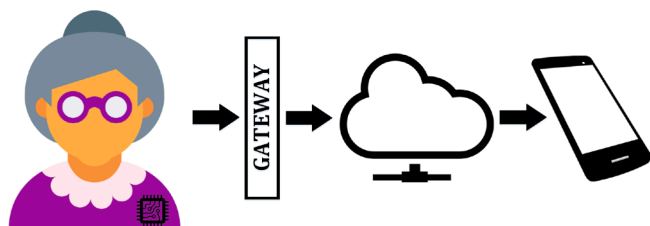

Fig. 3. General view of the monitoring system.

the user home and the information between the wearable device and the gateway is transmitted via the wireless local area network (WLAN); in the second solution, the wearable device transmit the information via personal area network (PAN) using a Bluetooth modem to the user cellphone, which works as gateway. Moreover, two different firmware modes were developed in order to reduce communication transmissions and increase the system autonomy.

All those alternatives and modes will be discussed deeply in the next sections.

2.1.1. Wearable device

Starting with the wearable device developed in this work, it was already commented in the introductory section that it is based on a smart t-shirt. The brain of the system is a microcontroller, that collects the information from various physiological sensors, performs a filtering process and transmits the information to the gateway via wireless. Next, the different components, its connections, the first prototype of the t-shirt and the firmware implemented in the microcontroller will be detailed.

The wearable device uses a low-power Lilypad microcontroller designed by Arduino and focused on wearable devices and clothing. Several components are connected to it: skin temperature (SK) sensor, electrocardiograph (ECG), galvanic skin response (GSR) sensor, accelerometer (ACC), micro SD module, a buzzer, the wireless transmission module (bluetooth or WIFI modem, depending on the solution) and a button battery to power up the full system. The electronic schematic for the second solution can be observed in Fig. 4. The schematic for the first one would be very similar (changing the bluetooth module for the WIFI module).

The electronic circuit was initially placed in the t-shirt using classical wires to connect the different components. However, due to the rigidity produced by them on the t-shirt, a second prototype was designed using conductive sewing wires that were internally sewn to the cloth. About the internal processing of the wearable system, it is divided in three steps:

- Read (R): in this first state, the microcontroller reads the information from all the sensors.
- Process (P): once the information is stored, in this step there are two processing modes (depending on the version implemented of the firmware). These modes are evaluated independently in the power consumption tests and are detailed next:
    – Local processing mode (LP): the microcontroller stores several samples from all the sensors (depending on the time window
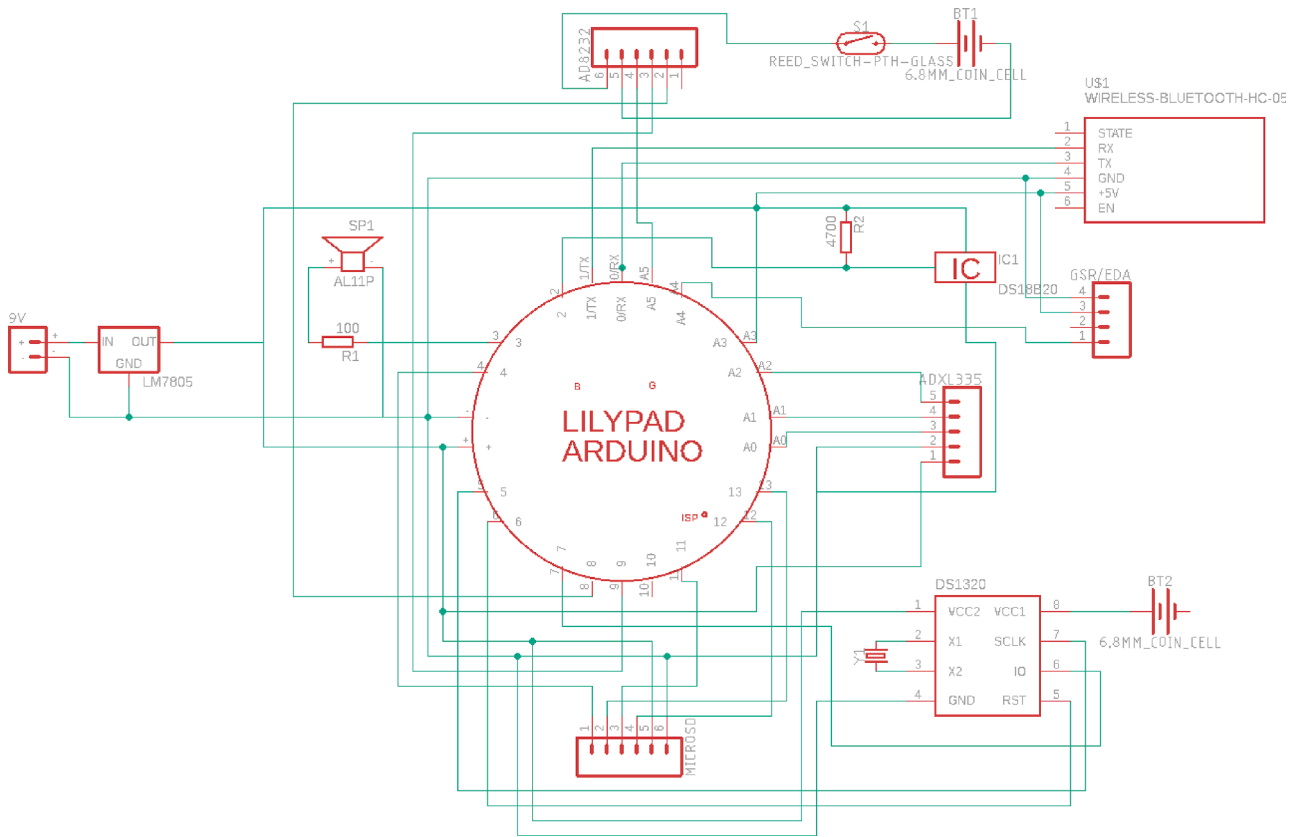
Fig. 4. Second solution's schematic connections for the intelligent t-shirt.

used) and extract high-level information from them. This information is: heart rate (obtained from ECG data), sweating variation (from GSR data), medium temperature (obtained from SK data) and fall prediction (obtained from ACC data). In this mode, the information is transmitted only if there is an abnormal situation or if one of those values exceeds the allowed limits. Those limits are configured in the system according to the user age, pathologies and doctor's diagnostic.

– Remote processing mode (RP): the information from all the sensors is filtered periodically (using a time window much smaller that the one used in the previous mode) and sent to the gateway without evaluating if there is an abnormal situation or not. The deeper processing process will take place in the raspberry pi (first solution) or in the cellphone (second solution).

It is important to clarify that the data collected by the device is stored locally in both processing modes considered, even using RP. Its purpose is related with avoiding the loss of information produced by a connection cut. So the data is stored locally until the connection is recovered.

• Transmit (T): the information processed in the previous step is packed in a unique frame that will contain all the sensors'

Fig. 5. Wearable device: (left) internal view of the t-shirt prototype; (right) firmware's state machine.
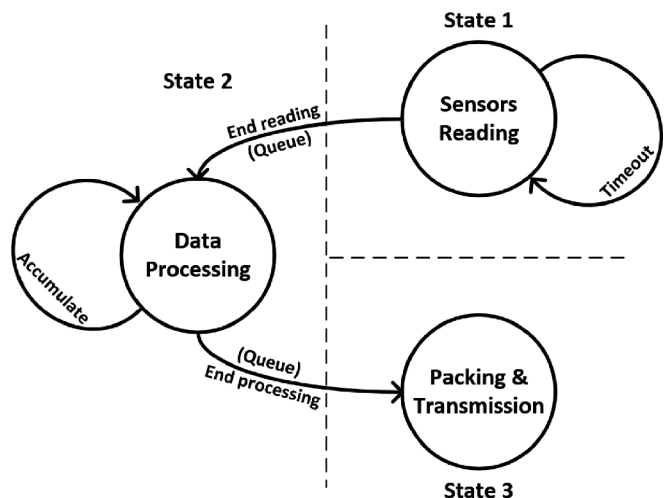
information separated with a delimiter byte (second mode) or the high-level information obtained locally (first mode). This frame includes an starting sequence, an ending sequence and a FCS field (Frame Check Sequence) in order to check that the information received is correct.

The electronic connections for the first prototype of the t-shirt are shown in Fig. 5-left, and the firmware's state machine used in the microcontroller is shown in Fig. 5-right. It is important to indicate that the state machine presented in Fig. 5-right is a general vision, but its "Data Processing" state varies depending on the firmware mode implemented: for RP mode, this state filters the information from each sensor using a fixed-size window; while, using LP mode, this state filters the information and integrates each sensor's data using a higher window size in order to process it and extract high-level parameters (heart rate in the case of ECG data, fall detection in the case of accelerometer data, sweating variation in the case of GSR data and skin temperature from the temperature sensor). Both modes will be detailed deeply in the next subsection.

2.1.2. Gateway

As detailed before, two different solutions have been developed in order to evaluate the best alternative for the goal we want to achieve. Each solution has its advantages and disadvantages and are evaluated next.

The first solution is focused on install a fixed gateway in the user's home (based on a Raspberry Pi), that received the transmissions from the wearable device (or devices if there are more than one user in the same house). This one is easier to install in a typical home (the user does not need to carry any additional device), but it needs the user to stay in his/her home. This solution (see Fig. 6-left) is useful for most of the cases, as dependant users do not usually leave home without supervision.

On the other hand, in the second solution (see Fig. 6-right) the gateway used to process and transmit the information to the cloud service is the user's cellphone. This alternative allows the user to go away from his/her home but he/she needs to carry the cellphone everywhere. This requirement may be petty, but elderly population not always have a cellphone and, even so, at home they do not carry it (so the system may not be able to establish a stable connection between the t-shirt's bluetooth modem and the cellphone if they are far away from each other).

Both solutions were developed, installed and tested, obtaining best processing results and transmission rates with the first solution (due to the computational power of the fixed gateway and the connection speed of the wired network). However, for economic reasons and after consulting several caregivers, the solution adopted was the second one.

So, as we need a notification and visualization app for the caregiver, this gateway implementation has been integrated in the same mobile application. In this way, the same app allow us to select if we are an user or a caregiver and, depending on that, it works in different ways. The final application implementation is detailed in the next section.

2.1.3. Application

As detailed before, the application has a double goal. On the one hand, is the main tool for the caregivers in order to continuously check the patients' status and receive notifications about abnormal situations. On the other hand, the app is used by the patients in order to transmit the information about the intelligent t-shirt. The communication between the patient and the caregiver is done through a Firebase cloud service (detailed in Fig. 7).

For the patient's version, and based on the microcontroller's firmware mode, it works like a communication gateway exclusively (if the microcontroller process internally the sensors' information), or it process the data too (if the microcontroller only sends the information received). The differences obtained by those modes will be evaluated deeply for the power consumption tests.

About the application itself, several characteristics may be observed. For both the patients and the caregivers, a logging interface was developed (Google or Facebook accounts can be used to create an account). It is shown on Fig. 8-a and -b. The other characteristics can only be observed using the caregivers' credentials. They can see the information about the physiological signals by selecting them independently (see Fig. 8-c) or even change the view between the different patients they have assigned (see Fig. 8-d).

But the most important characteristic of the work is the automatic notification system. Those notifications are received by the caregiver: they can configure what notifications they want to receive and from whom (see Fig. 9-left); and, when one of those triggers is produced, they receive an alert in the notifications' area of their cellphone (see Fig. 9-right).

In Fig. 9-right, the caregiver receive an alert from patient "Mama2" about a possible fall. The full communication flow starts when the patient t-shirt collects the data and send the information to the patient cellphone. Between them, the accelerometer data is processed and the system determines that the patient has felt. This event produces an alert communication between the patient cellphone and the Firebase cloud service, when the destination of this alert is selected and the notification sent. Finally, the caregiver receive the alert as shown in Fig. 9-right.

Summarizing the total amount of characteristics and possibilities that this system has, a flow diagram is shown in Fig. 10.

At this point, the full system has been detailed and it operates technically correct. But, in order to evaluate the goodness of our system, two main tests are performed: a power-consumption test, where the two different firmware modes are compared; and an usability test done to professional caregivers. Those tests are detailed next and their results are presented in the next section.

2.2. Testing the system

Due to issues related with the pandemic restrictions, the system has only been tested with six users (all of them over 65 years old) with six different caregivers. The tests performed determine that it works correctly. Temperature, ECG and GSR physiological signals' information
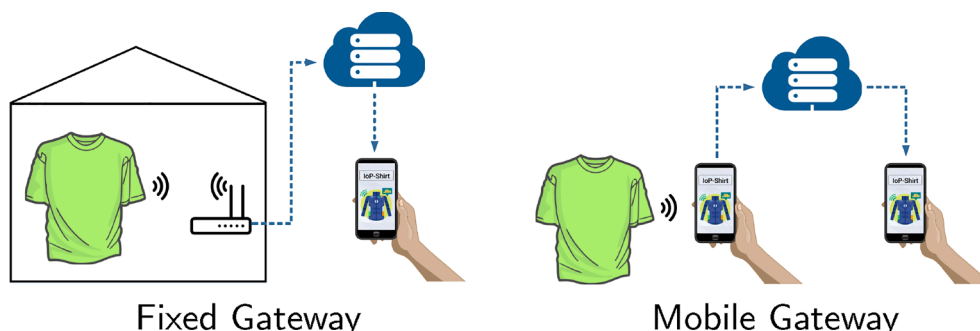

Fig. 6. Gateway alternatives: (left) fixed gateway implemented on a Raspberry Pi; (right) mobile gateway integrated in the user's cellphone.
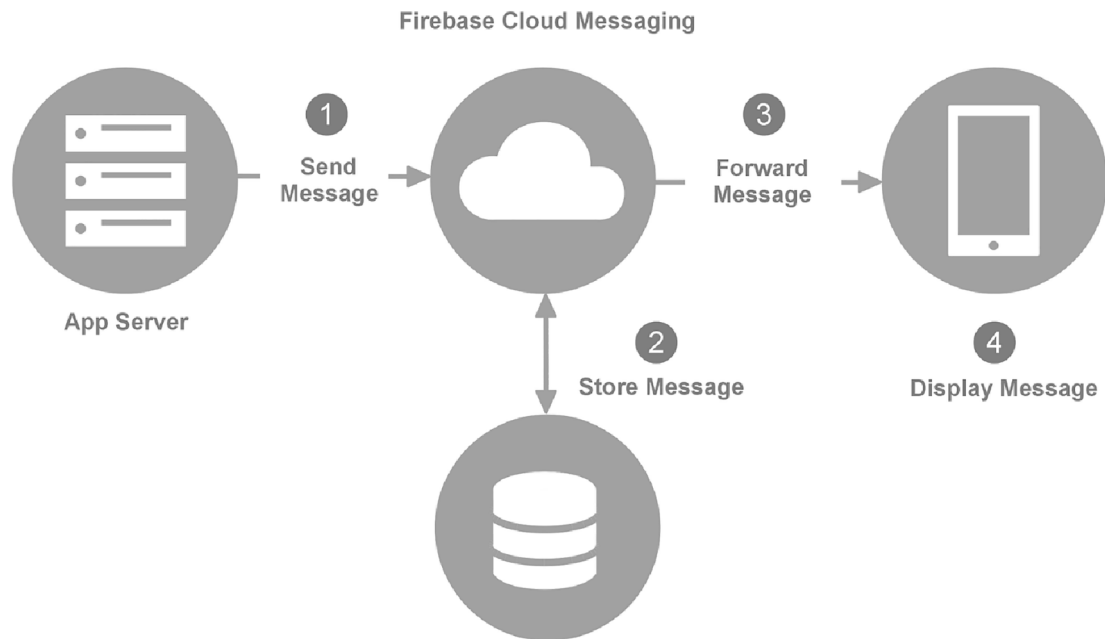
Fig. 7. Firebase Cloud Messaging communication between the patient and the caregiver.
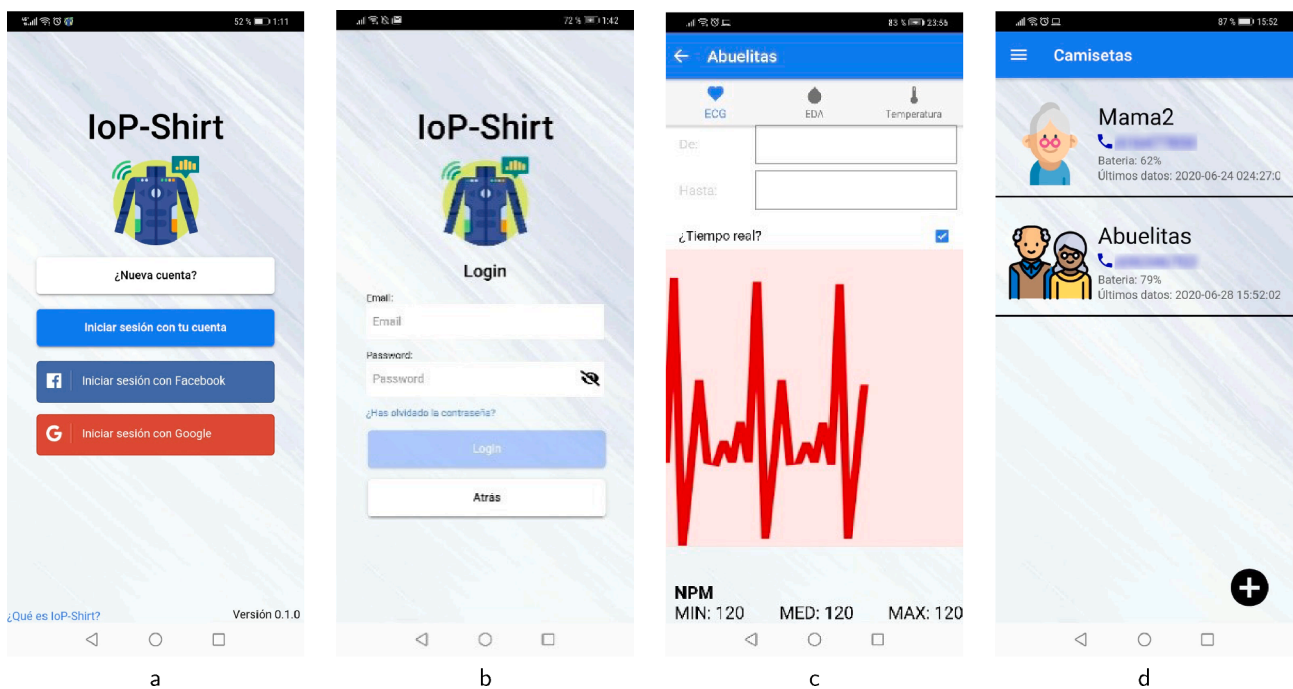

Fig. 8. App captures: (a and b) Logging interfaces; (c) ECG signal visualization; (d) patients list.

have been compared with commercial devices (Braun Thermoscan 3, Neulog NUL217 and Garmin HRM, respectively) and those results are presented in the next section. About the fall detector, tests include daily-live activities and fall simulations, corroborating the results visually.

The patients and users who have participated in the tests of this first version of the system are acquittances and relatives of the researchers. These participants always transmitted their full availability and never established impediments to the data processing that has been done in this work. Even so, two actions were carried out to ensure the privacy of their data and keep their rights intact:

- Before starting data collection, the purpose of the study was explicitly detailed to all participants, and they were provided with a consent form that both patients and caregivers signed individually.
- The data storage was carried out completely anonymously, and any person who accessed these data could only observe sex and age, in addition to physiological data, without being associated with personal and public identification data. This policy has been followed for both patients and their caregivers.

It is important to remark that the sampling process is not carried out in an invasive way and therefore does not imply any type of risk to the patients' health. Furthermore, most of the measurements taken in this
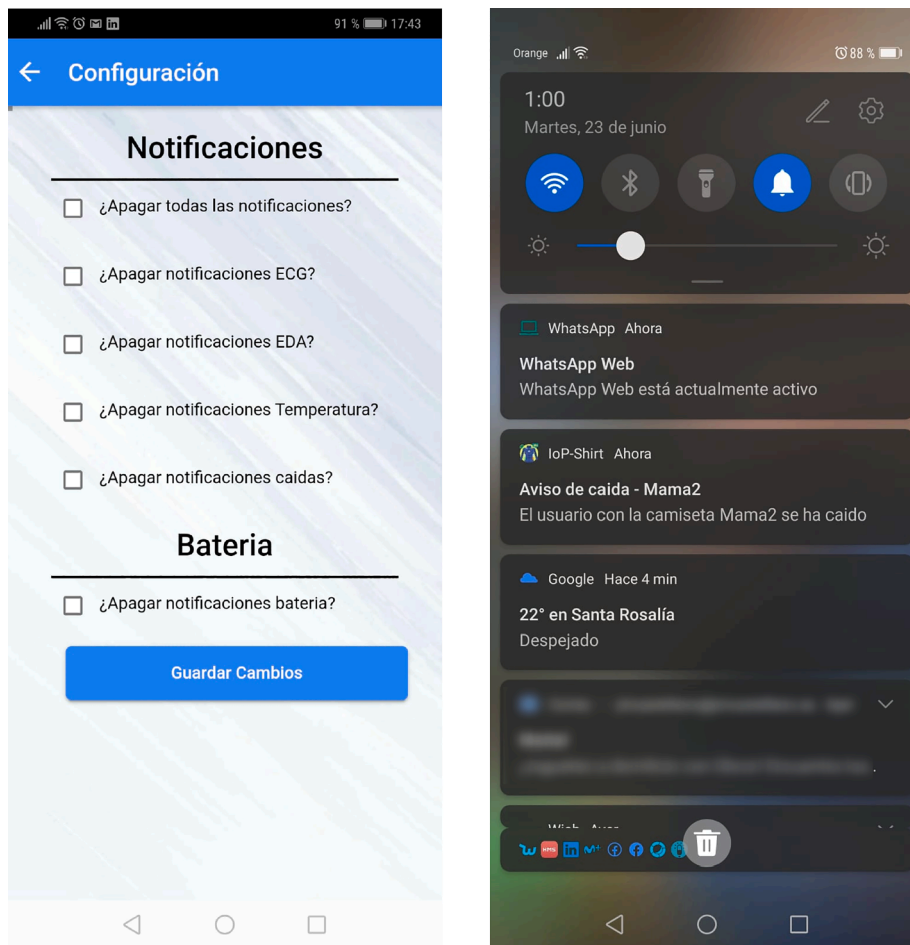
Fig. 9. Notifications configuration (left) and activation (right).

study are also used in commercial fitness systems, which are not medical devices and therefore have not gone through the detailed verification process that a medical device would require.

In a near future, when this system is implemented in a healthcare center, a more detailed process should be followed, involving the ethics committee of the participating hospital entity.

Regarding the tests performed for this work, they are related to the wearable system autonomy and to the usability tests done to the caregivers that participate in the testing phase. Both tests are detailed next.

2.2.1. Power consumption

To evaluate the energy efficiency of the device designed for this work, a power consumption study was carried out for each component independently and, finally, for the full wearable system. Moreover, as commented before, two different firmware's modes were developed: the first one process the sensors' data locally (in the device itself) and the second one transmit raw data to an external device which do the processing step.

On the one hand, the first mode carries out much less communication transmissions with the external device (which significantly reduces the power consumption), but includes a much more complex processing that implies greater power consumption. On the other hand, the second mode is completely the opposite: local processing is very simple (only a filtering process), thereby reducing consumption in this regard; but in this mode the communications periodicity increases, which increases the power consumption in the same way. These two scenarios can be observed in Fig. 11.

The comparison between both scenarios will be detailed in the next section taking into account the next aspects:

- Remote processing mode (RP):
  – Continuous transmission rate at 50 Hz.
  – 30-bytes communication frame.
- Local processing mode (LP):
  – Transmission only if an abnormal situation is detected: heart rate value too high or low, temperature too high or low, too much sweating or a fall is detected.
  – 8-bytes communication frame.

2.2.2. Usability

The integration of this type of system in society does not only depend on its functionality and/or its benefits, but also on the ease of use by users who are not experts in technology. It is therefore very important to carry out usability studies with the systems that are going to be made available to the population.

In this case, the tests carried out with patients and caregivers were used to consult their opinion about the system. Therefore, this usability study was carried out with the six caregivers who tested the system in its initial phase.

In order to perform a usability test that fulfil all the guaranties, several users need to perform several task repeating them several times during different days, and controlling the time spent in each task. After finishing those tasks, each user fills a survey that asks some aspects about the tasks performed. With that information and with the times spent in the tasks, we can apply some metrics that evaluates the usability of the system.

According to ISO/IEC 9126–4 Standard (and the new version ISO/IEC 25022) [22], the metrics to evaluate the usability of a product are essentially three: effectiveness, efficiency and satisfaction.
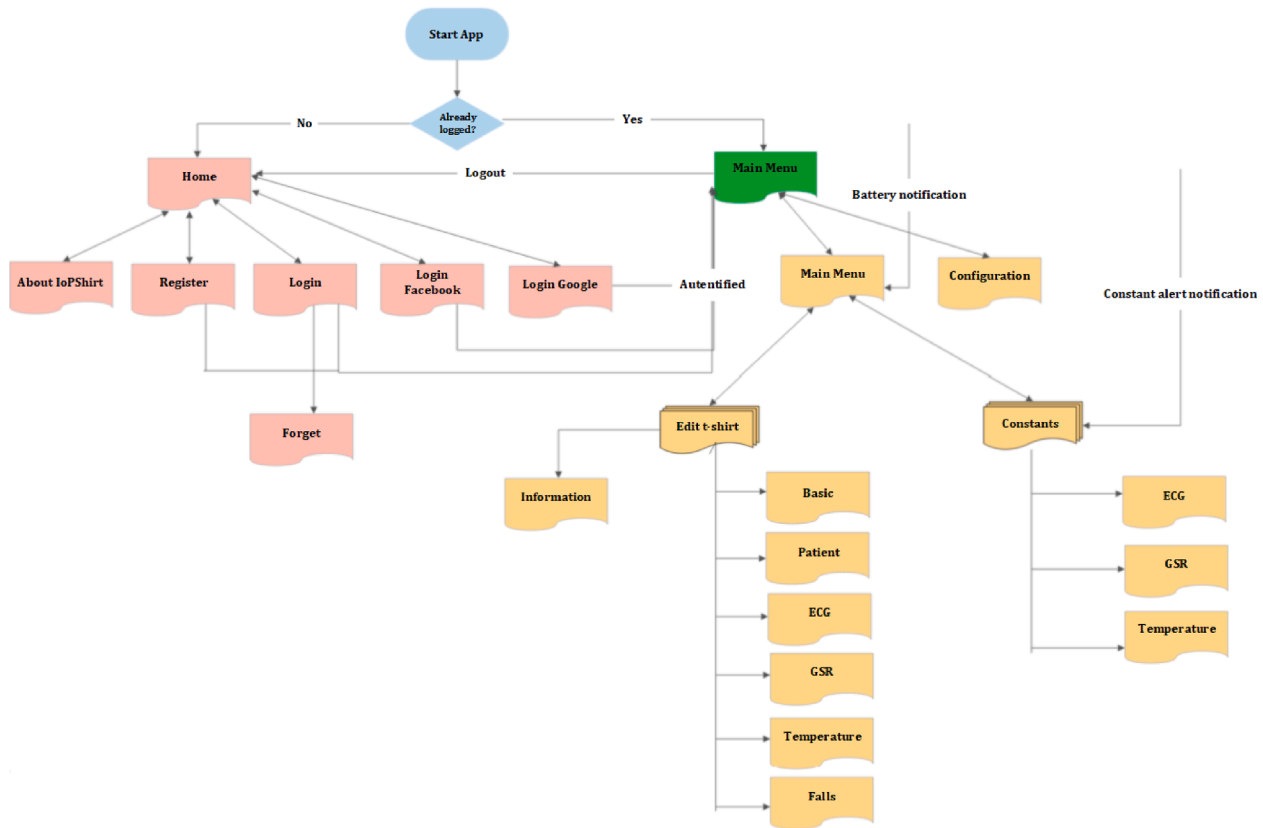
Fig. 10. Application's flow diagram.

- Effectiveness: accuracy and completeness with which the users achieve the specified objectives. Typical measurements include:
  - Number of tasks that can be performed.
  - Percentage of tasks completed successfully on the first attempt.
  - Percentage of users able to successfully complete each task.
  - Percentage of users who can carry out each tasks without asking for help.
- Efficiency: resources spent in relation to the accuracy and completeness with which users achieve the objectives. Typical measurements include:
  - Time spent on the first attempt.
  - Time to perform each task.
  - Time to do the task compared to an expert.
- Satisfaction: comfort and use acceptability. It refers to how users feel about the system. Typical measurements include:
  - Percentage of users who think it is beneficial for their field.
  - Percentage of users that voluntarily would use the product.
  - Percentage of customers who feel "in control" of the product.
  - Percentage of customers who would recommend it.

  So, to evaluate the usability, we performed a usability study formed by six main tasks: create user, create t-shirt, visualize sensors' values, change patient, subscribe to notifications, receive notifications. Al the tasks are done during five different days by each caregiver (who control the time spent on them); and, after each try, caregivers fill a survey. This survey contains some questions for each task and some in general:
- For each task:
  - Q1: Did you complete it? (answer yes or no)
  - Q2: Did you ask for help? (answer yes or no)
  - Q3: It was easy to perform? (answer 1 to 10)
  - Q4: How much time did you spent? (in seconds)
- In general:
  - G1: Is this product useful? (answer 1 to 10)

  - G2: Did you use this product in your work? (answer yes or no)
  - G3: Do you feel in control with the product? (answer yes or no)
  - G4: Would you recommend it to your colleagues? (answer yes or no)

In the next section the results obtained with this usability study will be detailed.

3. Results and discussion

In this section, the results obtained after evaluating the elderly care system will be presented and discussed.

It is important to take into account that the current pandemic crisis played and important role in the recollection and testing stages. Because of it, this system was tested only with a few participants; however, the results obtained are good enough to achive important results and conclusions.

Moreover, the prototype presented in this work is in an initial stage yet and, before the final integration in the healthcare system, it has been evaluated. Moreover, some tests proposed couldn't be carried out because of the pandemic situation.

3.1. System accuracy

Starting with the system performance, the accuracy of the sensors' data collected was evaluated. First, the information obtained from temperature sensor, GSR and ECG are compared with commercial devices (Braun Thermoscan 3, Neulog NUL217 and Garmin HRM, respectively): more than 100 different measures were taken from 10 voluntaries during daily-living activities (resting, walking, jogging, etc.) using the commercial device and our wearable device in parallel. The medium error obtained from each physiological signal and the standard deviation are shown in Table 2.
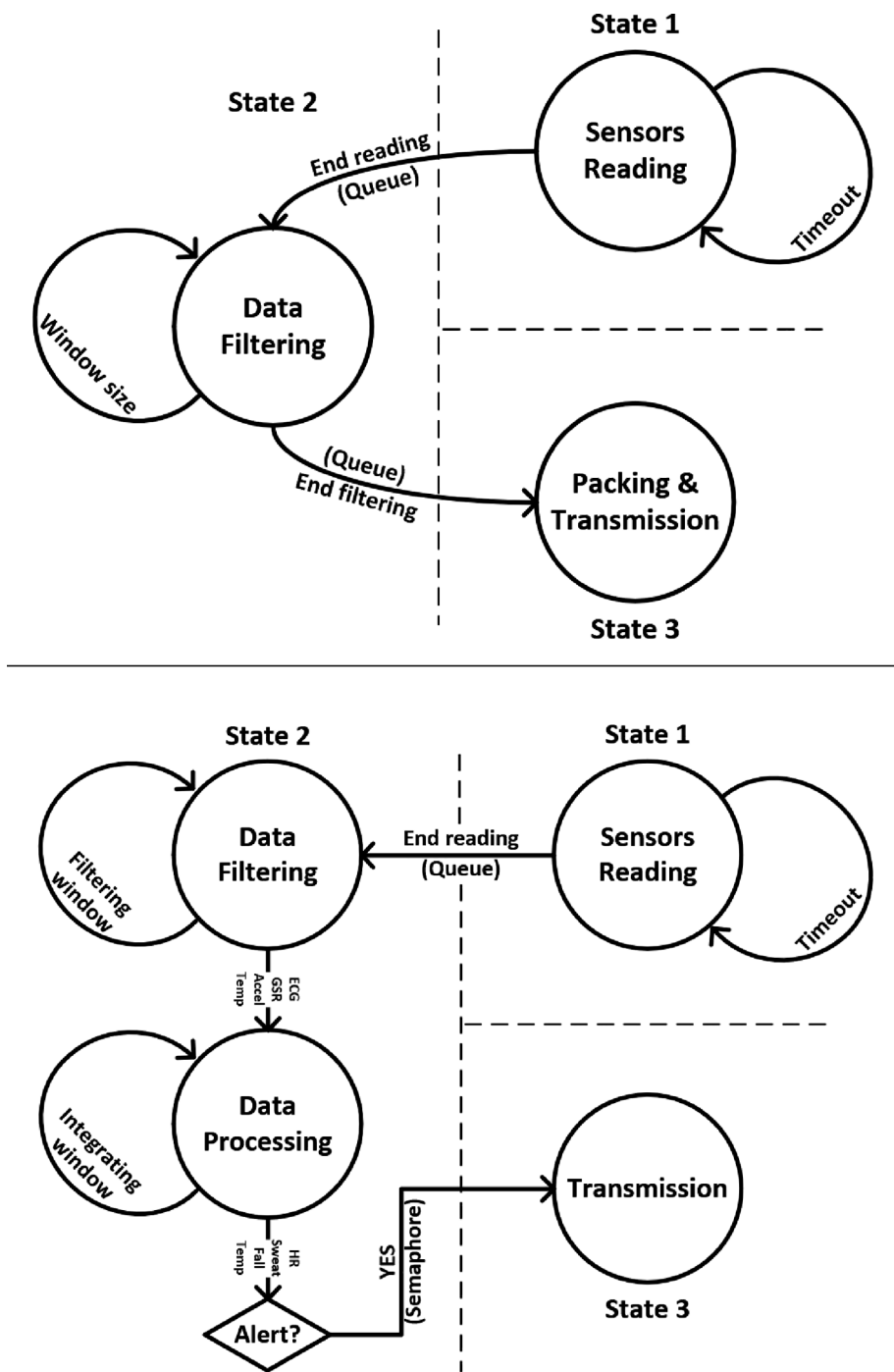
Fig. 11. Scenarios under study: (top) remote processing; (bottom) local processing.

Results shown in Table 2 indicates that our system's accuracy for Skin Temperature and ECG sensors is acceptable, obtaining an error less than 1.4% for skin temperature (between 2 and 3 degree tenths) and an error less than 3.7% for heart rate detected using ECG (between 2 and 5 beats/min). About the GSR sensor, results indicate that the sweating variation error committed for our system is high; this fact may be related to the initial calibration of the sensor, since we use several fixed resistors with a 5% error (instead of a 1% error recommended for these cases). However, our system indicates the sweating level in a qualitative manner (low, medium and high), so this error does not interfere too much in the result.

If we make a careful study of the results, it is interesting to see that the greatest errors obtained from the skin temperature and sweating

variation almost always occur in men; this may be due to the hair's resistance, which interferes with the sample collecting (carried out by superficial contact with the skin). So, with this theory, the errors obtained could be reduced in elderly people, as they usually have less hair on their limbs.

And about the fall detector, it works with a Decision Tree using some threshholds applied to the maximum magnitude of the acceleration vector. In order to test the accuracy of this functionality, the ten users do some daily-living activities (walking, resting, sitting, standing, etc.) combined with three simulated falls (front, back and sideway). The result of the fall detector was checked visually and the results are presented in Table 3.

Although the system detects 34 falls, only 28 are correct; so, the

Table 2
Physiological data accuracy. The arithmetic mean from the errors can be observed (with the standard deviation in parentheses).

User	Male/Female	Temp error (%)	Heart rate error (%)	weating var. error (%)
1	Female	0.9($\pm$0.2)	3.3($\pm$1.1)	9.8($\pm$2.3)
2	Female	1.2($\pm$0.4)	2.5($\pm$1.0)	10.0($\pm$2.1)
3	Male	1.7($\pm$0.6)	2.7($\pm$1.4)	13.7($\pm$2.7)
4	Female	1.0($\pm$0.3)	4.8($\pm$1.7)	10.4($\pm$3.0)
5	Female	0.8($\pm$0.2)	3.9($\pm$1.2)	9.9($\pm$2.5)
6	Male	2.4($\pm$0.7)	4.2($\pm$1.6)	17.2($\pm$4.6)
7	Female	1.4($\pm$0.1)	2.9($\pm$2.1)	13.5($\pm$3.9)
8	Male	1.5($\pm$0.3)	5.1($\pm$1.5)	14.1($\pm$3.3)
9	Male	1.2($\pm$0.5)	3.1($\pm$2.2)	11.3($\pm$2.6)
10	Male	1.3($\pm$0.5)	3.8($\pm$2.0)	12.4($\pm$4.1)
GLOBAL	All	1.34($\pm$0.38)	3.63($\pm$1.58)	12.23($\pm$3.11)

Table 3
Fall detector accuracy.

Activity	Falls detected	Accuracy (%)
Resting	0	100
Walking	0	100
Jogging	3	70
Walking up stairs	0	100
Walking down stairs	1	90
Sitting down	2	80
Getting up	0	100
Front fall	10	100
Back fall	9	90
Sideway fall	9	90
Total FALLS	34	93.3

system detects 28 of the 30 real falls, obtaining a 93.3% accuracy. However, as commented, the systems detects six wrong falls, so it have more than a 8% of false positive cases; those cases are important to be taken into account, although they are not critical to the caregiver (the dangerous cases are those in which the system does not detect a fall that has occurred).

The previous results were tested using commercial devices, but it will be very useful if those results are validated by healthcare professionals too. About that, it is important to mention that the current work is a prototype that is under testing and has only been tested in a laboratory setting with volunteer participants. However, it is common that the health professionals want not only the inferenced results but also the raw data. So, the validation process could be performed in the first stages of the integration phase by the professionals themwelves.

3.2. Power consumption

About the system autonomy, in the previous section two different modes where presented: local processing and remote processing. A power consumption study was done to each alternative and the results are presented next.

The autonomy of our system with the RP mode is up to 39 h and 34 min with a 800 mAH battery (almost 10 h with a 200 mAH battery). However, the LP mode autonomy depends on the number of transmissions and, taking into account other autonomy studies, more than 80% of the battery consumption is produced by the communications. So, Fig. 12 shows the system autonomy depending on the number of abnormal events detected. As can be observed, with no transmissions, LP mode has a power consumption around 27% of RM mode, obtaining an autonomy greater than 146 h with the 800 mAH battery (more than 36 h using a typical 200 mAH button cell, allowing to operate during a complete journey).

3.3. Usability results

Finally, the system was tested with the six real patients and caregivers commented in the previous section. Everyday, the caregivers have six tasks: create user, create t-shirt, visualize sensors' values, change patient, subscribe to notifications, receive notifications (access to them). After each day, caregivers filled one questionnaire about those tasks in order to evaluate the effectiveness and the efficiency of the system; and, after the whole testing period, the caregivers filled another questionnaire in order to evaluate the final product satisfaction. The questionnaires' answers are detailed in Table 4, and the final usability results are shown in Fig. 13.

As can be observed in Table 4, the most difficult tasks were "change patient" and "subscribe to notifications", but the results were both greater than 6/10. The rest of the tasks obtain good results, so almost all
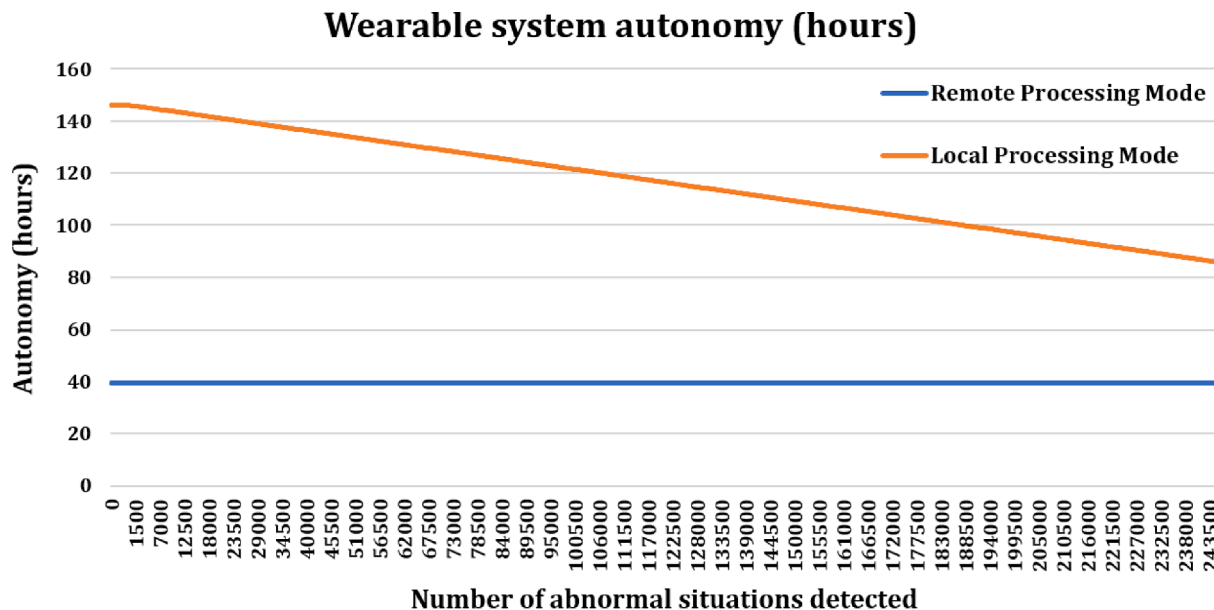

Fig. 12. System autonomy comparison between RP mode and LP mode using a 800mAH battery.

Table 4

Questionnaires answers. Question values Q1 and Q2 were 'yes' or 'no' in the questionnaires; but in this table we summarize the values from the five days, so we put a value between 0 and 5 indicating the number of 'yes' answers. About question Q3, we put the medium value from the five days.

Caregiver	Task 1			Task 2			Task 3			Task 4			Task 5			Task 6			General			
	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	G1	G2	G3	G4
1	5	0	9.6	5	0	8.6	5	0	10	5	0	9	4	1	7	5	0	10	9	Y	Y	Y
2	5	0	9.8	5	0	7.8	5	0	10	4	1	7.6	5	0	8.2	5	0	10	8	Y	Y	Y
3	5	0	8.8	4	1	4.8	5	0	10	5	0	8.2	4	1	6.6	5	0	9.2	8	Y	N	N
4	4	1	7.4	3	2	5.4	5	0	9	4	1	6.4	3	2	4.2	5	0	8.6	7	N	N	N
5	5	0	8.6	4	1	5.6	5	0	9	5	0	8	4	1	5.8	5	0	8.8	8	Y	Y	Y
6	5	0	9.2	5	0	9	5	0	10	5	0	8.2	4	1	6	5	0	8.8	9	Y	Y	Y
GLOBAL	97%	3%	8.9	87%	13%	6.8	100%	0%	9.7	93%	7%	7.9	80%	20%	6.3	100%	0%	9.2	8.2	83%	67%	83%

of the characteristics of the application are intuitive for the majority of the testers. These results are grouped and synthesized in Fig. 13.

According to Fig. 13 results, the three high-level usability metrics are evaluated next:

- Effectiveness: it is given by the tasks completed successfully and the external help needed. According to that, it exceeds the 90%, so the system can be used easily by the majority of the population.
- Efficiency: it is given by the time spent doing the different tasks and the comparison with an expert. Due to the need of a 43.17% additional time, it is not as high as the effectiveness and we obtain a 69.8%. This result is due to the lack of an user manual and the advanced age of some caregivers. So, we need to optimize the visualization of the user app in order to make it easy to find the controls, and we need to elaborate an user manual.
- Satisfaction: it is given by the general questions obtained at the end of the tests. This metric exceed the 80%, so the testing users think the product is useful and will use it. The final value is not so high due to the efficiency results; so, we think that improving the lacks detected in the efficiency metric is enough to improve this metric too.

After the usability test, we can affirm that the system proposed can be useful for the caregivers and solves the problems that were raised at the beginning of this work.

4. Conclusions

In this work, the society problem regarding the elderly care have been presented. Patients require continuous monitoring of their condition, while caregivers are responsible for several patients. This causes that sometimes dangerous situations occur when there is no nearby caregiver to attend the patient.

Trying to solve it, an IoT system based on a wearable device is proposed. It is worn by the patient and continuously monitor several physiological signals. This information is processed to obtain the patient's status regarding their heart rate, sweating, body temperature, and falling situations. This information is transmitted, through a cloud service, to the caregiver's cellphone, who would receive those alert notifications from each of his patients.

To test this system, three different tests have been developed: an performance test, a power consumption test and a usability test.

About the performance test, it is shown that the information from the heart rate, body temperature and falls have a high precision with an error less than 4%. However, the sweating sensor results shows a significantly higher error due to the resistance caused by body hair.

Regarding the power consumption test, two operating modes for the wearable's firmware have been evaluated: the first one process remotely the information, and the other one process the information in the microcontroller itself and only transmit the alets detected. While the remote processing mode allows an autonomy of more than 39 h, the local processing mode substantially increases this autonomy, exceeding 146 h (375% compared to the other mode).

Finally, the usability test carried out on six caregivers with six patients during five days and performing six different tasks, yields very interesting results. While effectiveness and satisfaction have high values, efficiency drops substantially due to the absence of a user manual and the lack of training for caregivers.

The presented work is evolving day by day in order to improve the sampling rate and precission and, in next versions, it will integrate more precise sensors, some of them digital, and a more powerful microcontroller with greater computational power to be able to implement more precise filtering algorithms.

Moreover, after the pandemic situation and the prototype improving stages, this work will be tested in the healthcare system.

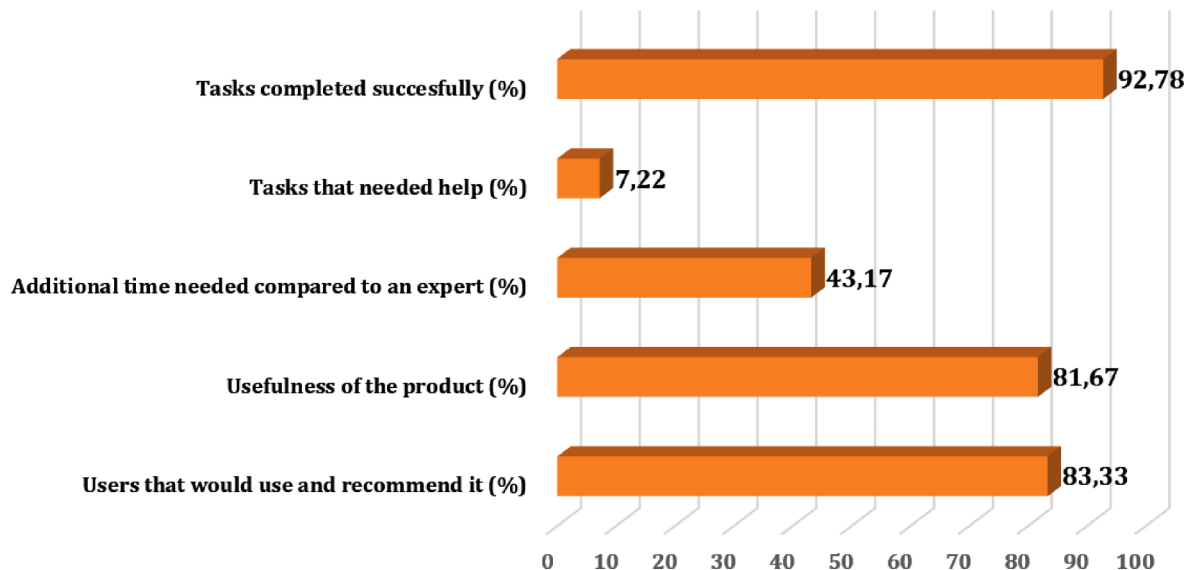# Usability results obtained from the questionnaires

Fig. 13. Usability results based on questionnaires answers.

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CRediT authorship contribution statement

Francisco Luna-Perejon: Conceptualization, Methodology, Software. **Luis Munoz-Saavedra:** Conceptualization, Methodology, Software. **Jose M. Castellano-Dominguez:** Conceptualization, Methodology, Software. **Manuel Dominguez-Morales:** Conceptualization, Methodology, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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