# We-Care: An IoT-based Health Care System for Elderly People

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***Abstract*—In a world with an accelerated population aging, there is an increasingly interest in developing solutions for the elderly living assistance. The Internet of Things is a new reality that is completely changing our everyday life, and promises to revolutionize modern healthcare by enabling a more personalized, preventive and collaborative form of care. Aiming to combine these two important topics, this work presents an IoT-ready solution for the elderly living assistance which is able to monitor and register patients vital information as well as to provide mechanisms to trigger alarms in emergency situations. Its effective low-power/low-cost and wireless characteristics turns this solution suitable to be used anywhere and by anyone, in a discrete and comfortable wristband. Experiments demonstrated a good system performance for the implemented functionalities, and regarding the autonomy we obtained an average battery lifetime of 306 hours (around 12 days). For the working range, the system have proved to perform well within a range of 60 meters before the out-of-range warning being triggered.**

***Index Terms*—Internet of Things (IoT), Health Care, Elderly Living Assistance, Monitoring Wristband**

## I. Introduction

The world is undergoing an unprecedented technological transformation, evolving from isolated systems to ubiquitous Internet-enabled 'things' capable of generating and exchanging vast amounts of valuable data [1,2]. This novel paradigm, commonly referred as the Internet of Things (IoT), is a new reality that is enriching our everyday life, increasing business productivity, and improving government efficiency [2,3]. In the IoT era, daily usage objects are becoming smarter, and start to play a key role in surrounding infrastructures. From a simple smart street lamp to a complex smart city [4] or from a simple industrial controller to a complex smart factory [5], this flourish of interconnected devices promise to drive a plethora of applications with technological, economic, and social prospects.

An important domain where IoT promises to drive significant changes and cause a huge impact is in health care systems [6]. The use of Information and Communication Technologies in healthcare scenarios have proven several advantages of continuously monitoring health behaviors [7], and the IoT paradigm is enabling a more personalized, preventive and collaborative form of care, where patients are monitoring and managing their own health, and the responsibility for health care is shared between patients and the medical staff [8]. The IoT has the potential to give rise to many medical applications such as remote health monitoring, chronic diseases, private health and fitness, and pediatric and elderly care [6]. Among this wide broad of applications, the health care of aging and incapacitated individuals, called ambient assisted living (AAL), is attracting specially attention, due to the expected acceleration of global population aging [9]. This kind of solutions can also be particularly helpful in rural areas, where the number and availability of emergency teams with a proper reaction is sometimes poor and scarce.

In the last few years, substantial research efforts have been made in IoT-driven healthcare applications, services, and prototypes. Nevertheless, the first steps towards this direction have their roots on wireless sensor networks (WSN) [7]. Suntiamorntut et al. [10] proposed a low-cost elderly assistive living system for private houses, while Redondi et al. proposed LAURA [11], an integrated system for patient monitoring, localization and tracking within nursing institutes. However, with the advent of the IoT, the ongoing trend is to shift from old-fashioned protocols to standardized IP-based networks. In [12], an IoT-aware smart hospital system (SHS) is presented and discussed, providing innovative services for the automatic monitoring and tracking of patients, personnel, and biomedical devices within hospitals and nursing institutes. Arboleda et al. [13] developed an IoT system for in-home health care services of elderly patients with chronic heart and respiratory diseases. The system consists of a single wireless sensor node capable of monitoring heart rate, temperature, oxygen saturation and electrocardiographic signs. The Carestore platform [14] is an innovative open-source platform for seamless healthcare device marketing and configuration. The Common Recognition and Identification Platform (CRIP), a component of the CareStore project, offers a sensor-based support for seamless identification of users and health devices.

There are also some smart wearable solutions for AAL available on the market. The BodyGuardian Heart [15] is a monitor responsible for collecting patient mobile cardiac telemetry (MCT) and cardiac event monitoring (CEM). The patient's data is automatically detected and wirelessly delivered to a monitoring center, through a smartphone. Doctors can access their patients' data, and review notifications via web through specific portals (PatientView and PatientFlow). Wellness [16] is system that combines sensors, mobile notifications and home automation to provide a secure and cost-effective

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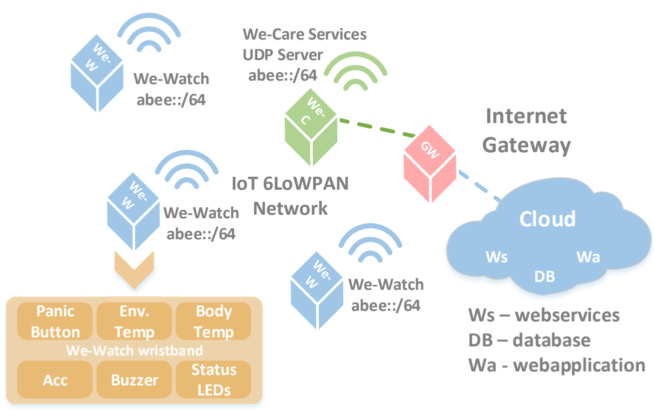


Figure 1. We-Care system architecture

option for independent living. Using real-time information from in-home sensors, the solution notifies family members or designated caregivers of unexpected changes in routines that may indicate an emergency. UnaliWear [17] is a smartwatch for older adults. It does not provide any health parameter monitoring, but it has an accelerometer for fall detection, and continuous speech to provide an active medical alert.

Aiming to contribute for a better elderly living assisting, we developed We-care, a wireless IoT-ready solution for elderly people that is able to monitor and collect patients important vital data, making it available to medical staff and/or the designed caretaker. The data is collected by the patients wristband and is sent to the caretaker monitor system, triggering alerts in the case of emergency situations such as falls, and the absence of important vital signs. The proposed system was developed taking in consideration the low-power and low-cost requirements, turning the solution suitable to be used by everyone at the comfort of their homes. Our solution is distinguished from others by its easy interaction and integration with IoT-enabled networks, offering a low-cost system that can be affordable by everyone, while providing the most important services of other related systems.

## II. System Architecture

Figure 1 illustrates the general architecture of the We-Care system. It is composed by three main components: the (1) We-Watch wristband, the (2) We-Care services board and the (3) cloud services. The We-Watch consists of a discrete small sized wristband that is used by the elderly person. It is responsible to monitor and collect data from the available sensors and send it securely to the We-Care board which is responsible to run the web services and interface the cloud when an Internet gateway is available. The wireless network implements a standard IoT stack and all the wristbands are IPv6 enabled, supported by the 6LoWPAN protocol. The We-Care board is responsible to receive all the collected data from the We-Watch wristbands and to run all the system services. In a case of an emergency it triggers an alarm to the caretaker, enabling a fast response to any possible problem. In the absence of Internet connectivity or the caretaker sharing the same local network, all the available services still run on this board, turning the We-Care system a standalone platform, independent from the Internet to work. When connected to the Internet through an available gateway, this board turns the system widely available, where all services and features are accessed also online, from anywhere and at anytime, through the developed applications. This feature enables the system to remotely monitor any elderly person without their physical presence. Detailed implementations of each component are discussed in sections III and IV.

## III. Hardware Devices

The first We-Care prototype, composed by the We-Watch wristband, the We-Care board along with the We-Watch gateway is depicted in Figure 2. The Internet gateway and the web applications are not illustrated.

### A. *We-Watch wristband*

The We-Watch wristband was firstly implemented using a SensorTag [18] from Texas Instruments (TI). It consists of a low-power development platform composed by the CC2650 MCU along with several on-board MEMS sensors. This multi-standard MCU supports Bluetooth LE 4.0 and 6LoWPAN over the IEEE 802.15.4 standard (2.4GHz), and it is supported by Contiki-OS [19], an operating system (OS) for IoT. Its small size and low-power features (it can operate for long periods of time when powered by a single coin cell battery) makes the SensorTag a great choice for deploying and testing the We-Care wristband. Despite other available tools, such as the eZ430-Chronos [20], they fail in providing IP connectivity and IoT stack support through Contiki-OS. The Contiki-OS was used to provide the full IoT stack support over the 6LoWPAN protocol.

Each We-Watch wristband can collect data from the available sensors, such as environmental and body temperatures, pressure, humidity, light, Received Signal Strength Indicator

Figure 2. We-Care prototype

(RSSI) values, accelerometer and push buttons. However, only data from the environmental and wrist temperatures, RSSI, accelerometer and push buttons are used. Connecting to an UDP socket with an UDP Server running on the We-Watch gateway, all the collected samples are periodically sent to the monitoring/alert services running on the We-Care board.

Each sensor can be used to implement a set of functionalities and services. The push button is used as a *Panic Button*, which can be pressed to immediately send distress messages to the caretaker, e.g., in emergencies or situations where the elderly person is lost and needs help to find the way back. The RSSI value is used to help in tracking the wristband and, along with an audio signal performed by the on-board buzzer, helping in determining out-of-range/disconnected situations. This parameter can be used in both sides of the communication channel, i.e., the We-Watch wristband and the 6LoWPAN interface in the We-Watch gateway. The *Fall Detection* system is implemented by reading the accelerometer data which is used to detect sudden movements, like falls, and also to track any movement activity performed by the elderly person. The temperature sensors, used to continuously measure the ambient and body temperatures, are also used by the *Body Presence Detector* module, which is able to detect the presence of the body. If the wristband is detached, the system triggers an alarm to the caretaker system, alerting the situation.

### *B. We-Care board*

The We-Care software services and cloud interface were developed using the TI SimpleLink CC3200 Launchpad [21] kit. The CC3200 System-on-Chip (SoC) consists of a powerful ARM Cortex-M4 CPU Core along with built-in Wi-Fi connectivity. For the software stack we used the TI-RTOS, a real-time operating system for TI microcontrollers. TI-RTOS enables faster development by eliminating the need for developers to write and maintain system software. Designed to work with the TI Simple-Link family, the TI-RTOS offers embedded TCP/IP and TLS/SSL stacks for securing internet communications, HTTP Server and other internet protocols. The We-Care board can act either as an Wi-Fi Access Point (AP), enabling any Station device on the same network to connect and access the available services, such as the caretaker mobile application, or as a Station, connecting the We-Care system to the Internet and the cloud services. Using the Station profile on the We-Care board, any caretaker application can access and remotely monitor all the wristbands registered on the system. The We-Care board runs the webserver, listening on Port 80, for remote client connections. The web application and data files, such as logs containing the received data from the wristbands, are stored in an SDCard connected to the board.

Although being possible to connect each We-Watch device from the outside network (as long as the network provides IPv6 connectivity), for security purposes, the We-Care board acts as a firewall, as it does not run or support routing services, i.e., services that allow the devices to be reachable from any device rather than the We-Care board.

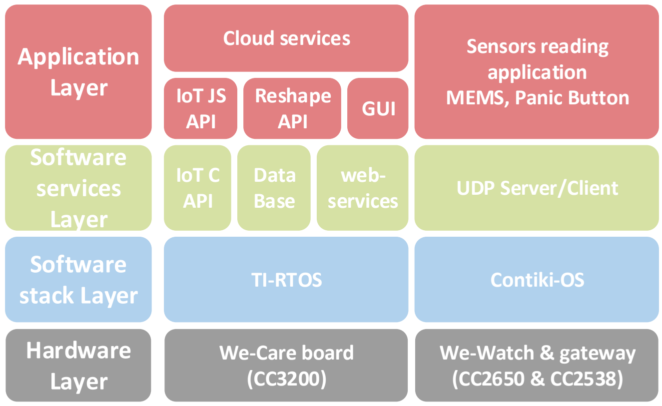


Figure 3. We-Care system software stack

### *C. We-Watch gateway*

Since the CC3200 only supports the IEEE 802.11 wireless protocol, the We-Care board needs to interface the 6LoWPAN network through an IEEE 802.15.4 compliant transceiver such as the CC2538/CC2650. This 6LoWPAN gateway runs a Contiki-OS UDP application which creates a socket with any wristband in the network, forwarding all the received IPv6 packets to the We-Care board. The UDP Server listens on the UDP Port 3000, accepting connections from remote clients on Port 3001.

### *D. Wireless charging dock station*

A wireless charging system was developed to integrate the We-Care system. Based on the TIDA-00881 [22] reference design, this technology eases the charging of the We-Watch battery since it only needs a base station to wirelessly charge it when placed over the base platform. This simple charging system helps the elderly person to charge the We-Watch without the need of cables or complex connecting systems.

## IV. Software Modules

Figure 3 illustrates the We-Care software stack. It can be represented by four simple layers: hardware, software, web-services and applications. The hardware layer represents the Board Support Packages (BSP) responsible to interface the hardware. For the different boards/hardware in use, i.e., the We-Care wristband, We-Care gateway and the We-Care board, this layer is provided along with the Contiki-OS and TI-RTOS libraries. The software layer is composed by the TI-RTOS and Contiki-OS protocol stacks and OS components. They provide, respectively, full IEEE 802.11 and IEEE 802.15.4 compliant software, as well an IP-enabled stack to interface the available communication interfaces. For the services layer, on the Contiki-OS side, we simply run an UDP Client/Server application to enable the message exchange between the We-Watch and the We-Watch gateway. On the TI-RTOS side, this layer implements all the web services, protocols, databases

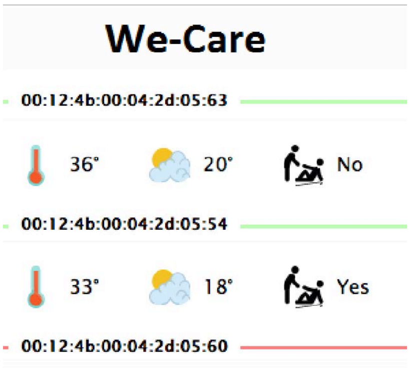


Figure 4. We-Care web application: caretaker interface

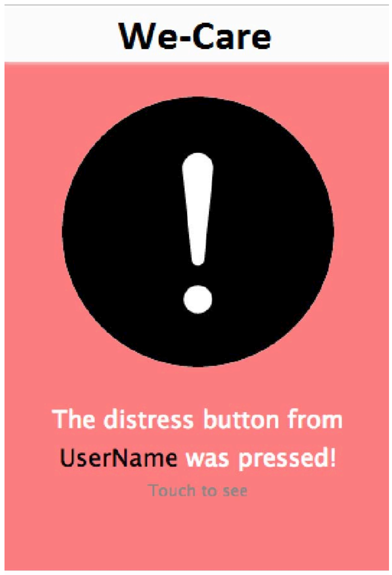


Figure 5. We-Care application: warning message

and the IoT C API which interacts with the IoT JS API implemented on the Application Layer. The Application Layer, on the TI-RTOS, generates the Graphical User Interface (GUI) to create the local webserver, which is able to display system status and data, and also sets all the application protocol messages to communicate with the cloud services and remote applications.

### *A. We-Care webserver*

The We-Care webserver was specially designed for running on the low-power CC3200 MCU, configured to handle four (up to eight) clients at a time. Its lightweight implementation provides two main APIs: the IoT.C and IoT.JS, written in C Language and JavaScript language, respectively. These APIs communicate with each other for dealing with the Machine-to-Machine (M2M) communication requirements.

### *B. We-Care web application*

The We-Care web application was also designed targeting the low-power requirements of the system. It only loads the required data and supports sleep modes which are activated when the applications is not in use. This way energy efficiency is increased, thus, resulting in an increased battery lifetime. This application also implements the GUI for supporting the caretaker interaction with the We-Care system. Written in HTML5 and CSS3, it can run in any browser and any device, without the need for extra applications or plug-ins. The application files are directly accessed from the SDCard through the File System API, rather than the SPI flash module presented on the board. This allows the application to be easily changed as the new files can be copied to the SDCard at anytime and allows the log data stored on the card to be accessed when needed.

Figure 4 illustrates an example of the simple interface available to the caretaker, displaying the information collected from the We-Watch wristbands, e.g., the body and environment temperatures and the Fall Detection system that alerts the caretaker in the case of an event of fall or abrupt movements. The colored lines next to the wristband identifier can tell if the device is online (green) or offline (red). The wristband IPv6 address is the name by default but it can be changed to any desired alias to ease the wristband identification.

For the distress messages, when the Push Button is pressed the application displays (Figure 5) a warning message followed by a sound alert in order to immediately notify the caretaker. Other alerts and messages can be configured to be sent to other designed destinations such as responsible person (rather than the caretaker) and medical emergency teams if the elderly requires urgent medical attention.

### *C. Securing the wireless communications*

Securing the wireless communications in IoT-based networks is mandatory. Protecting data from unauthorized viewers - which may intercept the IEEE 802.15.4 frames and/or inject fake data on the network, compromising the overall systems behavior - is essential in the We-Care application. The 802.15.4 standard defines optional cryptographic security suites for providing either confidentiality, integrity, or both, achieved by strong cryptographic algorithms, such as the Advanced Encryption Algorithm (AES). For securing the wireless communications between the We-Watch wristband and the We-Watch gateway, we used the *link-layer encryption library for IEEE 802.15.4 compliant radios* (LLSEC) provided by Contiki-OS, resorting the available on-chip AES-128 security modules. This implementation is based on the link-layer security library, provided by [23], and the deployed pairwise keys establishment schemes, which implements the Easy Broadcast Encryption and Authentication Protocol (EBEAP) and the Adaptable Pairwise Key Establishment Scheme (APKES) protocols.

Table I
CURRENT CONSUMPTION FOR DIFFERENT POWER MODES

| Power Mode | Description | Current (mA) | Time (ms) |
|---|---|---|---|
| 0 | Sleep Mode | NA | NA |
| 1 | Idle | 0,76 | - |
| 2 | Sensors ON | 6,47 | 100 |
| 3 | TX Mode | 25,77 | 5 |
| 4 | RX Mode | 33,12 | 0,3 |

## V. EVALUATION

### A. We-Watch battery lifetime

Experimental evaluation was performed in order to measure the energy consumption of the We-Watch wristband for different operation modes. From the obtained results the battery lifetime can be predicted. The measured values, along with their maximum duration, are presented in Table I. Although this MCU supporting Sleep and Deep Sleep power modes and the Contiki-OS being able to use them, they are not being enabled, thus this information is not available (NA). Since the application demands for 'always on' features such as the sensors sampling and message exchanging with the We-Watch gateway, only four operation modes were characterized:

- (1) Idle: This mode corresponds to the lowest current consumption mode and it is active for the most of the working time, helping saving energy. On the Idle mode the communications are OFF, but ready to be turned ON if the We-Watch needs to communicate with the gateway for messages exchange or network maintenance. However, in the case of sudden movements detected by the accelerometer (which may represent a fall) or if the distress button is pressed, the CPU is interrupted and the We-Watch immediately initiates the communications and reports to the We-Care board.
- (2) Sensors ON: This mode represents the sensors periodic sampling. It takes $100ms$ for reading all the sensors, with an average current consumption of $6.47mA$.
- (3) TX Mode: After collecting the sensors data, the We-Watch sends it to the We-Watch gateway. This operation takes, on average, $25.77mA$ and lasts, at most, $5ms$.
- (4) RX Mode: After sending the data to the gateway, the We-Watch stays in this mode for $0.3ms$ waiting for a data acknowledgment message before going to the Idle Mode again. The current consumption measured was, on average, $33.12mA$. This messages is needed for detecting loss of communication with the We-Care board and trigger the out-of-range situation.

Setting a communication and sampling-rate of 30 seconds (where the We-Watch performs all the aforementioned operations), the active mode (Sensors ON, TX mode and RX mode) draws, on average, $7.463mA$ during $0.105s$ and the Idle mode draws $0.760mA$ during $29.895s$. This leads to an average current consumption of $0.784mA$. With a standard rechargeable coin cell battery of $240mAh$, the estimated battery lifetime is calculated as follows:

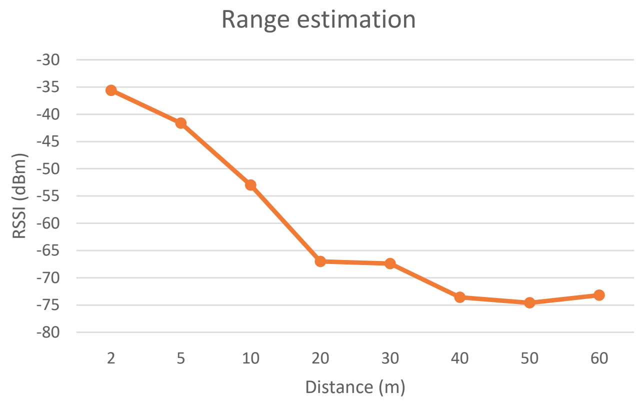


Figure 6. Range estimation test

$$BatteryLifeTime = \frac{BatCapacity(mAh)}{TotalConsumption(mA)} \quad (1)$$

$$BatteryLifeTime = \frac{240mAh}{0.784mA} \quad (2)$$

$$BatteryLifeTime = 306.12h \quad (3)$$

The expected battery lifetime is about $306.12h$, that is, around 12 days without being replaced or recharged. This gives enough time to the caretaker replace the battery or the We-Watch wristband, while keeping the system services and features. If the elderly person is able to perform the replacement and recharge the We-Watch itself, it can simply do it by using the wireless charger provided with the system.

### B. Performance Checks

*1) System availability:* In order to test the system availability to operate and its ability to adapt to conditions changing on the application scenario, we conducted some tests with the presence and absence of the Internet gateway. In the first case the We-Care board started the Station profile and the caretaker can always connect directly, or if in the same network, to the system. When the Internet gateway is available, the We-Care board activates the AP profile, expanding its connectivity to the cloud.

*2) Out of Range:* This functionality guarantees that the system is always connected and the elderly is on the range of the desired area. If the We-Watch wristband loses connection with the We-Care board, after a 60 seconds period of tries, both devices will trigger a sound alarm until the wristband returns to its range and is able to communicate again with the We-Care board. The performed tests consisted in using this functionality in a indoor environment at the range limit of the wristband. Figure 6 depicts the performed tests, where the out-of-range alarm is triggered based on the calculated RSSI. For reference purposes, the correlation between the distance and RSSI is displayed, which can help, based on an indoor environment to calculate the maximum system range. On a normal operation environment, the system range can go up to 60 meters before the out-of-range alarm is triggered.

## VI. Conclusions and Future Work

The world is embracing an unprecedented technological trend for connecting billions of devices. The Internet of Things is a new paradigm that is enriching our everyday life, and promises to drive significant changes and cause a huge impact in modern healthcare, by enabling a more personalized, preventive and collaborative form of care. In this paper we presented We-Care, an IoT-based health care system designed to monitor and collect vital data on elderly people. The system is able to detect falls, as well as the absence of vital signs, triggering alerts in case of emergency situations. The wearable device, to be integrated on a simple, discrete and comfortable wristband, offers a suitable solution to be used by any elderly person at home. The developed web application collects all the data retrieved and sent by the wristband to the server, and is also able to remotely alert the caretaker or medical staffs in the case of emergency events. The stored data can later be used for analysis, which may help medical staff to trace the evolution of their patients. The adopted IoT architecture enables the WE-Care system to co-exist with existing technology, since it follows a standardized protocol stack.

Work in the near future will focus on the addition of new sensors to the wristband in order to collect data from other vital parameters such as the blood pressure and the heart rate. This will be particularly helpful to determine the evolution of patient's medical condition as well as to find patterns that may indicates the evolution of some disease. Since the system was only tested with 8 We-Watch wristband nodes, more experiments shall be conducted in order to evaluate the systems behavior, in terms of performance and connectivity, both at the MAC and transport layers. The results will help in evaluating the scalability of the solution in terms of the supported number of We-Watch network nodes, as well as the capacity of the We-Care webserver application to handle such number of nodes. From a different perspective, we will after look at the privacy and security issues relating to medical data, and as it flows from the connected 'things' to the cloud. We will focus on the low-end devices and develop a TrustZone-based solution, similar to the one that we develop and propose in [24], for the latest generation of (low-end) ARM Cortex-M processors (e.g., Cortex-M23).

## VII. Acknowledgments

This work has been supported by COMPETE: POCI-01-0145-FEDER-007043 and FCT - *Fundação para a Ciência e Tecnologia* within the Project Scope: UID/CEC/00319/2013. Sandro Pinto is supported by FCT PhD grant SFRH/BD/91530/2012. Tiago Gomes is supported by FCT PhD grant SFRH/BD/90162/2012.

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