System Architecture for Home Muscle Rehabilitation Treatment

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Abstract. The constant loss of functional capacity due to aging is a serious problem that can severely worsen the quality of life. Among the possible treatments, muscles electrostimulation can be a viable option because it is cheap and easy to access. With the evolution of wearable devices and the Internet of Things, this paper proposes a system architecture that enables an electrostimulation treatment to be performed at the patient's home. For that, a scenario is presented in which the physiotherapist sets the treatment parameters online and the patient performs the electrostimulation sessions using a wearable with biofeedback sensors. To test the proposed architecture, a prototype capable of simulating a muscle rehabilitation treatment was implemented. The prototype was successful in performing the proposed scenario, following the defined rules for electrostimulation and collecting biofeedback at the same time.

Keywords: System · Architecture · Wearable · Muscle rehabilitation · Home treatment

1 Introduction

The World Health Organization (WHO) informs in each report that the elderly population is constantly growing worldwide. Thus, the constant decrease in mobility due to aging, usually associated with lack of exercise or poor quality of life in youth, is a severe problem that becomes more relevant every year [5].

Concerned about this, the WHO created a baseline to inspire and guide technological advances in the decade between 2021 to 2030 idealizing healthy aging. Within the guidelines, improving functional capacity is seen as the key to longevity with greater dignity, avoiding the need of caregivers and providing a better quality of life. Furthermore, data-driven solutions are presented as the path to scalable and accessible answers to the problem addressed [9].

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The traditional treatment for mobility rehabilitation is regular physical exercise, improving the performance of strength, endurance, and flexibility. However, some pathologies such as cardiovascular disease and neuromuscular problems can make this treatment unfeasible for the elderly [1].

An interesting solution positioned as an alternative to traditional training could be electrostimulation. This treatment is generally applied to improve functional capacity, preservation and recovery of muscle mass [2]. However, electrostimulation treatment for the elderly is considered new and requires a visit to the clinic for a session that usually takes 10 to 40 min to complete [4].

In recent years, the use of wearable electronic technology to improve health has been increasingly accepted. In the literature review produced in 2020, Lou et al. [7] point out that this new technology will change traditional diagnostic methods, bringing a revolution to medical devices. The wearable healthcare system has unique advantages such as instantaneity, flexibility and the ability to carry sensors easily and non-invasively. Thus, it creates the possibility of treatments being carried out remotely and portable.

Among the advances presented, we can highlight the development of wearables capable of tracking biophysical and biochemical signals, such as body temperature, body movements, blood pressure, among others. The continuous collection of physiological parameters of patients' lives provides opportunities for different areas of science, such as Data Processing and Artificial Intelligence (AI).

In this context, the study here reported proposes a system architecture that uses a electronic wearable to make treatment for muscle rehabilitation to be viable to execute at home. The proposed architecture aims to provide the mechanisms necessary to operate a device capable of receiving a set of electrostimulation rules to perform muscle rehabilitation and collect biofeedback data during treatment. This patient-centered approach intends to generate new opportunities for the physiotherapists analyze different data sets.

With this, it is expected to make possible the development of personalized treatments for muscular rehabilitation at the individual level. The main requirements that the architecture should satify are described below:

- Ensure fluid data collection via biofeedback sensors transmitting to a intermediate layer, usually the patient's smartphone.
- Define a data protection strategy, as medical systems deal with sensitive information.
- Develop mechanisms that facilitate the construction of data analysis and enable the application of machine learning algorithms.

The project under discussion contributes to society by offering an alternative that can serve as a key for reducing pressure on health services. The success of treatments at home for muscle rehabilitation implies a reduction in the cost of travel, especially for older people with motor difficulties that need help to move.

This document is divided into five more sections. Section 2 discusses the literature review, describing a few studies that guided us in the construction of the architecture; Sect. 3 describes the proposed architecture, detailing its components and connections; Sect. 4 describes the technologies used to implement a first prototype and the microcontroller used to simulate the wearable; Sect. 5 discusses a set of tests; Sect. 6 reports the main conclusions and future work.

2 Literature Review

Sundaravadivel et al.[10] reported that the functional requirements of healthcare systems should be defined by the acting components integrated into the system. For example, a temperature monitoring system can vary its operation depending on the frequency applied. Non-functional requirements can be classified into performance requirements and ethical requirements. Performance requirements are attributes that can determine the quality of the health system. Ethical requirements are attributes develop to ensure patient privacy and safety.

Ivanov et al. [3] analyzed 15 health monitoring systems (HMS) architectures seeking to understand the differences in the approaches found. The authors report that, primarily, theses systems must guarantee uninterrupted monitoring and constant data transmission between the acquisition system and a server. However, several challenges such as system scalability, network performance, data processing, can hinder the full functionality of these systems (Fig. 1).

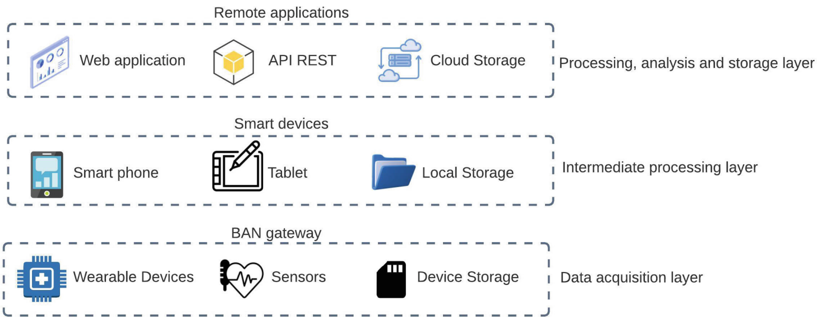

Fig. 1. Three-layer HMS architecture. adapted [3].

This study report that HMS generally have 2 or 3 layers. The first layer is dedicated to data acquisition, where the data will be collected via sensors and usually managed by a microcontroller. The intermediate layer consists of additional devices with data processing and transmission capabilities, including buffer management and compression. The last layer is referred to cloud computing, that can process large amounts of data and provide to the interfaces.

Usually, HMS architectures that have two layers exclude the middle layer, transmitting sensor data directly to the cloud. An example can be seen in [11], the approach develops a device that interprets signal from electromyogram sensors for automatic pain assessment through facial expressions. The device is configured in advance to communicate with the network gateway directly.

Manogaran et al. [8] develop an architecture based on Internet of Things concepts for a smart health ecosystem. The study divided the architecture two. The first is responsible for dealing with big data technology; The second is created to ensure the integration of fog computing with cloud computing.

3 Architecture

From the literature review, the architecture of a system was designed aiming to fulfill two main objectives. The first goal is to build a computer application that allows part of the treatment to be carried out in the patient's home. We believe that through the correct set of equipment it is possible to carry out an easy-to-use home treatment for the elderly.

The second goal is to offer to the physiotherapist, after each treatment session, the opportunity to explore clinical data for the development of personalized treatment. A set of clinical data can be explored in this context, such as motion sensors during the session, electromyographic sensors to capture muscle activity, forms of symptom monitoring, and others.

The information that will be stored is highly sensitive because it is concerned with the patient private data. Thus, the minimum security requirements must comply with the best practices for protecting sensitive data, segmenting the storages and mitigating possible cybernetic attacks. Considering this, the architecture shown in Fig. 2 has seven main components that were designed to achieve the initial goals.

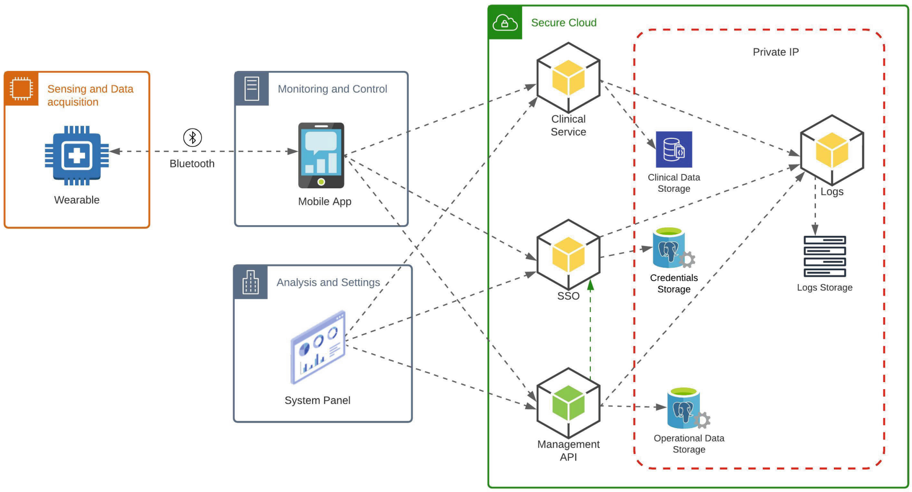

Fig. 2. Architecture

The proposed system is based on a three-layer architecture, using the smartphone as an intermediary device. Despite this, we split the interior of the secure cloud layer into two layers, making it possible to consider this architecture as four layers. This division guarantees that only the components that need external communication are available with public IP. Components that need to be more secure, such as databases and the logging service, are separated and only available on the private network. The functionalities and roles of each component are the following:

Wearable: Component that includes sensors for biofeedback data acquisition and the actuator. The purpose of this component is to perform the developed muscle stimulation treatment and send data to mobile app.

Mobile Application: Intermediate application between the wearable and the cloud. Its main functions will be: receive the stimulation protocol from the cloud and providing it for wearable; organize the data received by the treatment session and send it to the cloud; provide and collect the patient information.

System Panel: Administrative panel for professionals to manage patients and treatments. On this website, the physiotherapist will be able to visualize and adapt the electrostimulation plan. In addition, it will be possible to view the biofeedback acquired by the wearable and respond to messages from patients.

Clinical Service: Service that stores and processes the clinical data of patients. This information are: patient characteristics and medical history, clinical reports and biofeedback collected by wearables during sessions.

Management API: A module capable of managing and providing the necessary resources for the operation of the mobile app and the administrative panel. For example, managing patients, professionals, messages, equipment and others.

Single Sign-On (SSO): Component responsible for generating the access and refresh tokens. The purpose of SSO is to provide a single point of authentication within the architecture, thus ensuring that access of the multiple services is secure and transparent.

Log Service: Component required to maintain log integrity across the entire architecture. The intent is that all components provide logs periodically for this service, creating a unique auditable and secure access point.

The proposed architecture seeks to meet the needs of a physiotherapy treatment with electrostimulation for muscle rehabilitation. To better understand the architecture's capabilities, it was elaborated a scenario that must be performed by the system actors (physiotherapist and patient) for the treatment to be successful.

The design aims to reduce medical consultation, however, regular face-to-face meetings with specialized professionals are essential in this scenario. Thus, it is expected that the first sessions will be accompanied by a physiotherapist, who will adjust the parameters that allow greater comfort and safety to the patient. Afterwards, it is expected that the patient can continue the treatment at home, using the wearable and the smartphone.

Once the accompanied sessions are over, the physiotherapist should create a new treatment session via the panel and set the parameters that should be used for the electrostimulation. Then, the patient will be notified that a new session is available and the date when it should be performed. When the time comes, the patient calibrates the wearable with the help of the mobile app and performs the treatment. The flow chart in Fig. 3, shows the action cycle of the planned home treatment sessions.

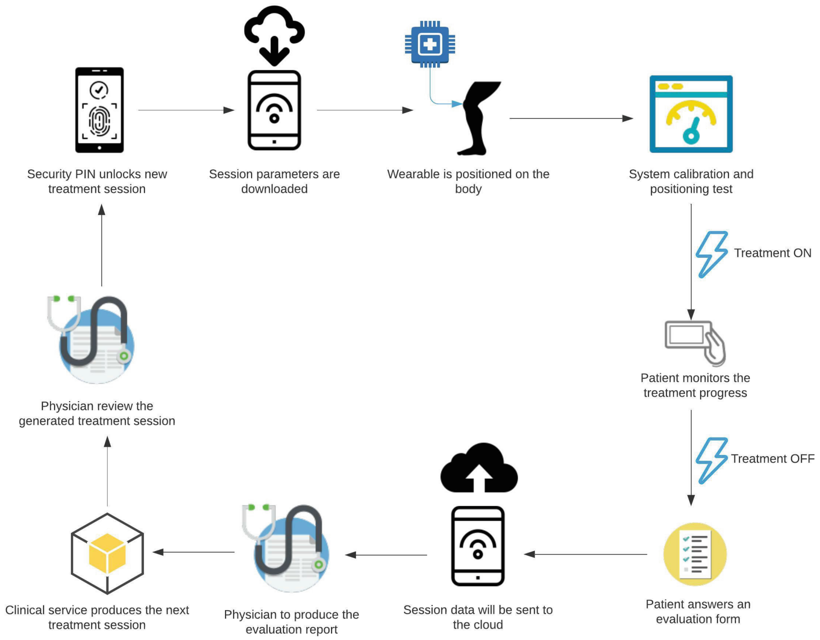

Fig. 3. Cycle of actions of the home treatment sessions.

After the session finished, the patient should answer a short questionnaire about the session and send the data to the cloud. In this way, the physiotherapist can access online how the patient reacted to the treatment through the biofeedback data and write an evaluation report. In this step, to illustrate the application of artificial intelligence in our system, a service that suggests plan for the next session was included in the flowchart as can be observed in Fig. 3. Then, the physiotherapist simply review the parameters before making the new session available to the patient. This cycle of actions should be repeated until the treatment comes to end.

3.1 Sensitive Data Protection

As already seen, the architecture contemplates the methodology of micro services, with this the data will be divided according to the operational needs of each service. Thus, the patients' personal data, such as addresses, phone numbers, responsible doctor, among others, were stored under the management API. The clinical data, such as treatment plans, recommended treatments, disease history, diagnoses, among others, were stored in the clinical API.

To maintain data integrity, the identifiers of each entity must be different in each database. This ensures that if both database systems are hacked, the attacker would not be able to link which diagnosis belongs to which patient, minimizing the impact.

To maintain the data relationships between the systems, the pseudonymization technique was applied. This technique allows the identity of subjects to be hidden from any outsourced services by assigning pseudo-identifiers. Thus, the third-party services are not able to relate the pseudonyms to the real identifications, so they do not recognize the author of the data provided. If a client application needs to recognize the identity of the data, a grant of access is requested. If the request is accepted, the triggered services returns the data that can be queried by the client app that requested it [6].

The relationship of the clinical API and the Management API can be understood as outsourced services to each other. Thus, when a mobile app wants to access either of the two services, it must send in the header of each request the access token provided by SSO service. Inside this token, three main pieces of information will be stored, the role the user belongs to, and two encrypted packets. The first packet is encrypted by the public key of the clinical API with the pseudo-anonymized identifier for the clinical API. The second packet follows the same logic, but encrypted and pseudo anonymized for the management API.

In this way, when a request is made, each service can open the packet with its private keys and search in their data for information that correlates with the sent identifiers. This ensures that the only ones who could discover the relationship between the two databases are the owners of the information, that is, the ones who should really have access.

4 Prototype for Home Treatment

Seven virtual machines (VM) based on Ubuntu Server 20 were allocated to apply the designed architecture. Only three VMs of the architecture have IPs in the public network; these machines have a different system module available, being Clinical Service, Management API, and SSO respectively.

The four remaining VMs were allocated in an internal network, allowing access only for the three public IP VMs. A database was installed in a different

VM for each module, being MongoDB for the Clinical Service and Postgres for the Management API and SSO. The Logs service and its database were installed in the same VM, since the module does not need a Public IP.

The Clinical Service and the Management API were developed from scratch using the Python programming language and the Flask framework. The open source solution Keycloak was used to provide the SSO service. Keycloak is a tool that can be installed from docker and has a user-friendly interface for adding secure authentication strategies.

For the administrative panel a web application was developed, the language used was Javascript with Angular JS Framework. With access restricted for the physiotherapist user role, only the essential functionalities were implemented such as: registering patients, treatment plans and treatment sessions.

The mobile application was developed using the Kotlin language defining Android 5.0 Lollipop as the minimum version of the smartphone operating system. In addition, the app require a WiFI connection to receive the parameters of the electrostimulation treatment and a Bluetooth Low Energy (BLE) connection.

To simulate the wearable device, a system was developed using the ESP32 microcontroller integrated with an electromyography (EMG) sensor. Electromyography is the technique in medicine used to monitor the electrical activity produced by a muscle. In this system, the sensor is used to collect real-time biofeedback from the muscle during treatment. As this system is a prototype, the electrostimulation was represented by a blinking led.

The wearable system was designed to be able to perform three main tasks. The first task is related to data collection, in which it is necessary to collect samples from the EMG sensor at 1000 Hz. The second task is to transmit the collected data to the smartphone in real time. The third task is to reproduce an electrostimulation treatment, including receiving a sequence of parameters and counting the correct time through the required frequency. These tasks were divided into two processing threads, one thread for the first and second task and the other for electrostimulation.

5 Tests

To test the proposed architecture, a scenario was designed that mirrors the actual environment expected for home treatment. Thus, a patient was registered by the administered panel and a treatment session. At this point the tool is not yet able to provide a wide range of settings for the physiotherapists, however it is able to provide the configuration of the duration, intensity and time interval between each stimulation. With this, a treatment with a duration of 1 min was defined to test the capacity of the architecture.

Initially, the treatment parameters were received from the cloud into the mobile app and a BLE connection was established with the wearable system. When the treatment is started, the mobile app sends every 8 s the next 10 s of stimulation, so that the wearable ends the treatment when the parameter vector is finished. Since the BLE protocol allows a maximum transmission of 517 bytes per packet and each EMG data occupies 2 bytes, we defined that the wearable should send a packet every 200 samples.

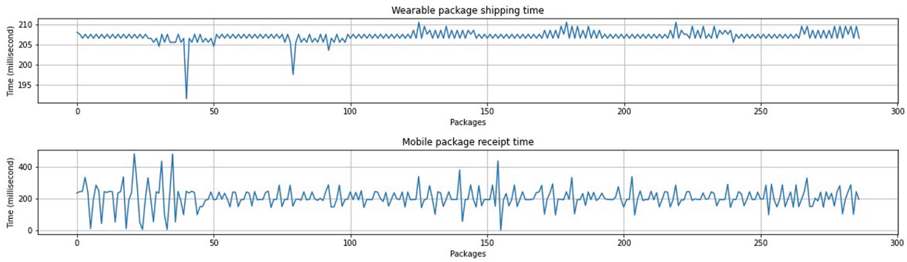

Fig. 4. Package exchange time between wearable system and mobile app.

As we can see in Fig. 4, with the low cost and low power consumption microcontroller it is possible to maintain the processing of the electrostimulation and the data transmission successfully. The average packet time presented in the two graphs is 206 ms, this implies an average delay of 6 ms to assemble each processed packet. Moreover, as the averages are equal, this tends to mean that the time lost during transmission was irrelevant.

To verify that the biofeedback was being collected correctly, the EMG sensor was positioned in the vastus medialis muscle of a healthy individual. During the 60 s of treatment the participant remained seated on a bench and performed the leg extension movement 5 times without being electrostimulated. After the session ended the data was sent to the cloud and processed in python using the jupyter notebook and the library biosignalsnotebooks.

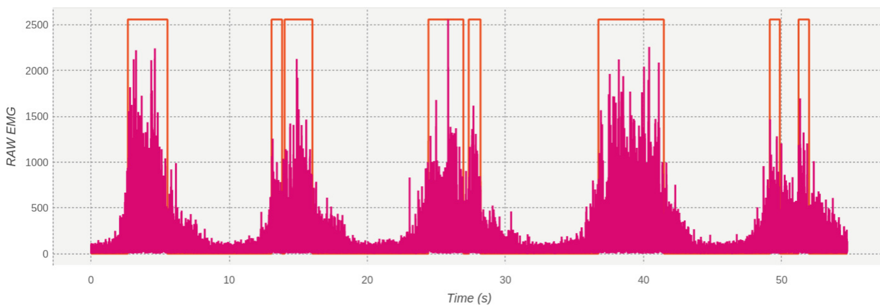

Fig. 5. EMG of muscle contractions during test treatment

Figure 5 shows the EMG signal collected by the wearable during a treatment test. After processing, it was possible to clearly visualize the moments of muscle contraction during the treatment. This graph is an example of information that is expected to provide for the physiotherapist to evaluate the patient's performance and propose the next treatment session.

6 Conclusion

The architecture proposed in this paper was designed to meet the needs of a physiotherapy treatment with electrostimulation for muscle rehabilitation. In addition, the system can also serve as inspiration for any system that needs to operate wearables and handle highly sensitive data.

The prototype developed demonstrates the ability of the architecture to follow the proposed scenario for home treatment. The tests performed were successful in following defined rules for electrostimulation. Acquisition tests have also been administered in the clinic by experts and have obtained the same results as shown in this paper. Furthermore, it was demonstrated that with only one electromyography sensor it is possible to provide relevant data to follow the patient's behavior during the treatment session.

For future work we intend to improve the administrative panel and develop a case-based recommendation algorithm to assist the physiotherapist. In addition, we hope to soon be able to test the electrostimulation on patients in a clinic.

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