Ambient Intelligent Model for Life Reinforcement

Patrícia Andreia Graça da Silva Santos

Abstract—The future of healthcare is an important issue involving several organizations, companies as well as research groups. As people live longer and acquire various chronic diseases, the burden on society will increase. While some serious situations require patients to be followed and monitored professionally, most patients with chronic illnesses can avoid disease worsening if they become more aware of their lifestyle choices and the impact those choices have on their well-being. Advances in technology enable us to design better, less intrusive, more user-friendly and less intimidating privacy systems. This work introduces a model for an intelligent Cyber-Physical System (CPS) environment that can notify the user about her/his well-being, interact with the environment to adjust the ambient comfort levels, and allow caregivers to monitor her/his health condition. The consistency of the model was evaluated through case studies, analysing how well it supports a solution to the problem, by comparing the obtained results with the objectives proposed.

Index Terms—Internet of Things (IoT); CPS; Healthcare; Ambient Assisted Living; Smart Wearables; Well-being;

1 Introduction

With the increase in life expectancy, the world population is projected to reach 9.7 billion by 2050 [1]. As people live longer and acquire various chronic diseases, the burden on society will increase. This weight can have serious consequences such as the overload of health services. To meet this challenge, the health sector is changing. The industry is moving from the reactive approach to health conditions to a more proactive approach. The objectives of providing better health services and automatically improving the quality of life of citizens, lead us to consider those based on the IoT and CPS concepts. Advances in technology enable us to design better, less intrusive, more user-friendly and less intimidating privacy systems. Daily monitoring allows, for example, the generation of processed events that can reveal important information about the person's condition, such as changes in heart rate, high blood pressure and stress. These ideas have been envisioned in the concept of **eHealth** which includes the application of information and communications technologies across the whole range of functions that affect the health sector. As a result of this evolution, a new combination is being adopted where the IoT concept intertwines with the concept of an intelligent CPS environment to reform healthcare and well-being and to provide people with these services in their smart homes. This revolution then brings a new concept called Ambient Assisted Living (AAL) [2].

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1.1 Motivation

Over the years several IoT platforms have been created for the most varied applications for the healthcare like is showed in **??**. But these platforms are designed for a particular type of support. In addition to this type of solutions are often not fully immersive, is this the user notices that the platform is present. Given this scenario, one solution for this could be an intelligent environment for reinforcement of emergent, proactive life that takes into account the monitoring of the individual not only with the objective of detecting possible situations of health risk as well as monitoring their well-being.

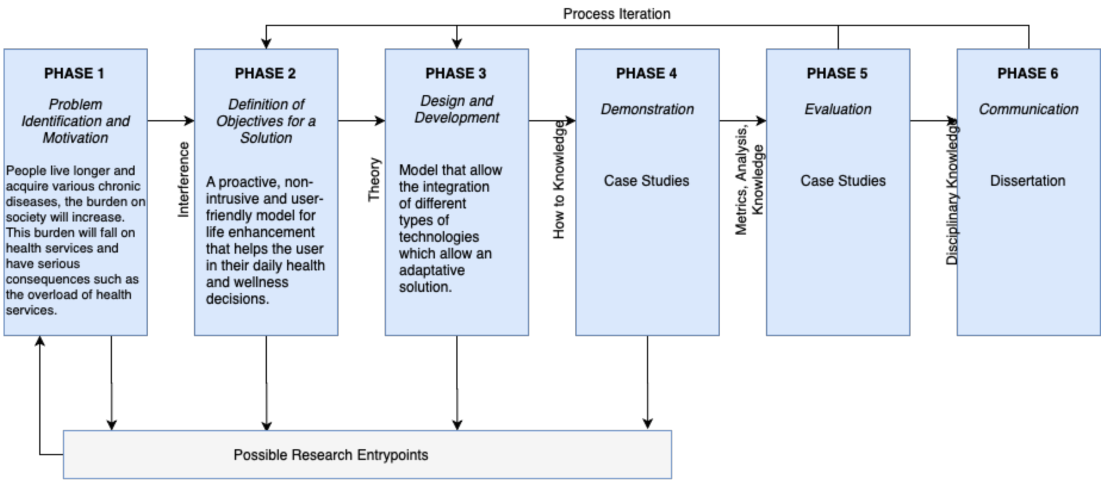

Figure 1. DSRM Process (adapted from [3])

1.2 Research and Design Methodology

n order to present a rigorous and scientifically justified model I used the Design Science Research Methodology (DSRM) described in [3]. The figure fig. 1 illustrates the relation between the structure of this work and the DSRM methodology.

1.3 Objectives

This thesis aims to present an model to an intelligent environment for life reinforcement. Therefore, this work intends to: list the requirements that a platform like this has to have; describe the essential components of the architecture of a platform that integrates several devices and services of data collection with communication with the user;show how to measure physical and environmental signs that may influence the well-being of the individual; analyze which external factors have the greatest influence on the individual's well-being by analyzing the results of a survey done on an arbitrary population sample; describe how to combine vital and environmental measurements can trigger adaptive actions on the platform; illustrate an example of environment model by demonstrating a test environment and case studies.

2 The Actual View

The Frost and Sullivan predicted that the expansion o smart healthcare products will be 348.5 billion dollars market by 2025 [4]. In this moment are ongoing many researches and works, and the ideas for improving these systems are many. Electronic Health Record (EHR) is one of the most significant products of smart healthcare, as this product gives a different meaning for addressing big-data issues.

The largest enterprises in the market are also revolutionizing the digital health with their ideas. *Intel* is leading with it's steady development of innovative technologies from data analysis to improving the home environment for the elderly population [4]. An artificially intelligent computer system was created by *IBM's Watson* described in [4].

In the way to keep digital health research on a large scale *IBM*, *Apple*, *Johnson & Johnson* and *Medtronic* have become partners [4] to improve the quality of the technological services for health since the quality of data caption, data treatment to better health apps [5].

Google has a life-sciences division [4] named *Verily* which creates tools that improve the data collect and organize health data. This way *Verily* can make health data useful for people enjoy healthier lives [6]. The *Qualcomm Life* enables the delivery of medical devices data to the nearby database partner [4].

Samsung has a digital health initiative that consists of open-source hardware and software platforms where there is a collaborations of smart sensors, algorithms, and data-processing techniques [4]. The *ResearchKit* of *Apple*, is an open-source framework that helps researchers in apps development and in medical research [4].

Smartwatches or bands, are examples of wearables that have been revolutionizing the market. Examples of that are products like *Fitbit*, *Pebble Time* and *iWatch*.

Those were the more futuristic views presently in the companies' perspectives and investments in this area.

2.1 Wearables, Sensors and Actuators

The first step in the direction of a smarter and personalized healthcare is undoubtedly the continuous monitoring of a person's physical parameters that allow precept the physical and mental person's conditions. Today, already exists thousands of devices and gadgets on the healthcare wearable market that collect this type of data and could help users to live a healthier and better life. Examples of these healthcare wearables for a healthy lifestyle are: *Pebble Time* family of smartwatches, that has one application named Pebble Health that measure your sleep [7]. *PIP* is a small device that allows you to give feedback about your stress levels [8].

These two examples are one choice possible to connect to other smart objects that could actuate in accordance of device's information.

2.2 Protocols in M2M and IoT

Such as previously mentioned the things around us in an intelligent environment need to interact with each other. However, the real question is what language or protocol do all these devices need to have to communicate with the Internet. The protocols that are currently used on the Internet cannot be directly used in these devices, because of short range low power wireless requirement of this devices . As such a new set of protocols which can be catered to the requirements of the Machine to Machine (M2M)/ IoT world had to be created. But with the purpose and goal of develop technical specifications which address the need for a common M2M Service Layer that can be readily embedded within various hardware and software, and relied upon to connect the myriad of devices in the field with M2M application servers worldwide, appears the One Machine-to-Machine (oneM2M) initiative described in [9].

One of the most important parts in communications are wireless technologies that are the basis of smart healthcare networks, so they have been a great bet for development and improvement. Some technologies such as Wireless Fidelity (Wi-Fi), Bluetooth Low Energy (BLE) [10], IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) [11] and Radio-frequency identification (RFID) [12] have played key roles in the exchange of information between different devices. But other technologies have helped in this field like is shown in **??** [13]–[16].

2.3 Data Storage and Data Processing

In the e-health monitoring systems, huge amounts of health data are quickly and simultaneously uploaded. This situation lead us to the concept of Big-Data, which was created to store, process and manage large volumes in the shortest time possible or even in real time. The Health Cloud, like the *Xiamen Healthcare Cloud*, is capable of storing data, save the health records and electronic medical records in Cloud data center. This allows storing a huge amount of data accessible anywhere at any time [17].

2.4 Security

The security is a theme very important in all fields but when we talk in health, security is the most important. In [18] we could learn what the essential requirements an e-health system needs to has. They are confidentiality, integrity and availability.

2.5 User Interfaces

The user interfaces have been a challenge in this area, because they have to be more intuitive, aesthetic and not conductive to error. They have the mission to present the health info to the user.

2.6 Examples of Healthcare Apps and Services

Some of examples that inspire me to create this model are:

- **Cooey Preventive and Pesonalize Healthcare** is a complete, smart platform for connected and collaborative care which allows users automatically log their medical data through bluetooth entitled devices.
- **Health Vault by Microsoft** helps users to gather, store, use, and share health information for them and their family members, putting the user in control of user health information.

2.7 Model Requirements

After analyzed the research carried out in this chapter I was able to define the requirements to the model.

For our model the *functional requirements* are the following [2]:

- **Data Generation:** integrated data generation subsystem (collection of physical parameters), where the sensors are fundamental;
- **Processing and Storage Subsystem:** subsystem with large data storage capacity, data handling support, raw data communication or processed data. This system should be too, an independent technology subsystem of communications in an network subsystem. This subsystem must provide the generation of high level abstraction from raw data. This way, it is possible to have one smarter, personalized and connected healthcare. The higher level that processing and storage subsystem must have the capacity to analyze the consumer's demand and choose if it should communicate raw data or processed data.
- **Consumer Subsystem:** where the user can receive recommendations from his particular doctor or caregiver, he must supports the discovery of resources to discover the M2M devices present in the data generation subsystem and select the appropriate ones for data collection
- **Device Manager:** that tracks the registered devices and their settings.
- **Appropriate Access Control Policies**: must be applied to allow authorized users to take advantage of customized healthcare solutions for both local users and institutional users.
- **Notifications Service:** to allow the user to act on behavioral cues.
- **Actuation Subsystem:** this system allow the user interact with the environment (e.g., smart home) based on the received notifications.

The system *nonfunctional requirements* (performance requirements and ethical requirements) are:

- Low power
- Quality of service
- Higher efficiency
- Scalability of the system to upgrade to newer versions and technologies
- Higher level of security for user's physical security
- Higher protection of user's personal data

2.8 Discussion

This project aims to present an independent decision-support model that can work for any user (individual or institutional) and with the highest level of scalability possible. For this I will take into account all type of sensors, actuators and wearables both environmental and physical of the user. In terms of protocols, I will not specify any particular ones because complete environments with several types of sensors, actuators and wearables can use different protocols; in terms of processing and storage I will assume that the solution is cloud based and that it abstracts from all the algorithms and considerations; concerning safety such implementation is being developed in parallel, in the research work of Eduardo Delgado, a MSc student of the Master Degree in Information Systems and Computer Engineering of Instituto Superior Técnico, entitled "Trusted Ambient Intelligent for Life Reinforcement ", with the objective of developing the security algorithms and the security considerations of this type of system. In terms of user interface I will demonstrate an design example where this type of service can be provided.

3 Model Design Proposed

We can identify four essential layers (Technology Layer; Access Gateway Layer; Middle Layer; Application Layer) to this model. **Technology Layer:** this layer is composed by various physical devices like wearables, sensors, RFID Tags, embedded systems and others. This layer realizes functions like collecting and processing information. The collecting function includes collect data from social network using Application Program Interface (API)s of different "Things".

Access Gateway Layer: the main function of this layer is computing. Here is made the route to messages, the communication between platforms and enable various services like data publishing and subscribing the data provided by various sensors.

Middleware Layer: this layer is the connection between the internet layer and the application layer. The majority of the information that is processed, cleaned, transformed, normalized and optimized is sent to the cloud directly.

Application Layer: through middleware this layer delivers various application services to the users like analytics, visualisation and Graphical User Interface (GUI)s.

3.1 Architecture of Big Data Management

In analyzing the requirements described in **??**, we can identify eight essential steps to tackle healthcare big data on a model such as this. They are the follow:

- **Data Sources**
- **Data Acquisition**
- **Transformation Operations**
- **Data Storage**
- **Analytics**
- **Middleware**
- **Information Consume**
- **Security and Privacy Management**

In the architecture design presented in Figure 2, the main components and interactions are showed.

3.1.1 Data Sources

The responsible for data generation are the data sources which in our model could be **User Information**, **Mobile Apps**, **Health Signs** and **Environment Sensors**.

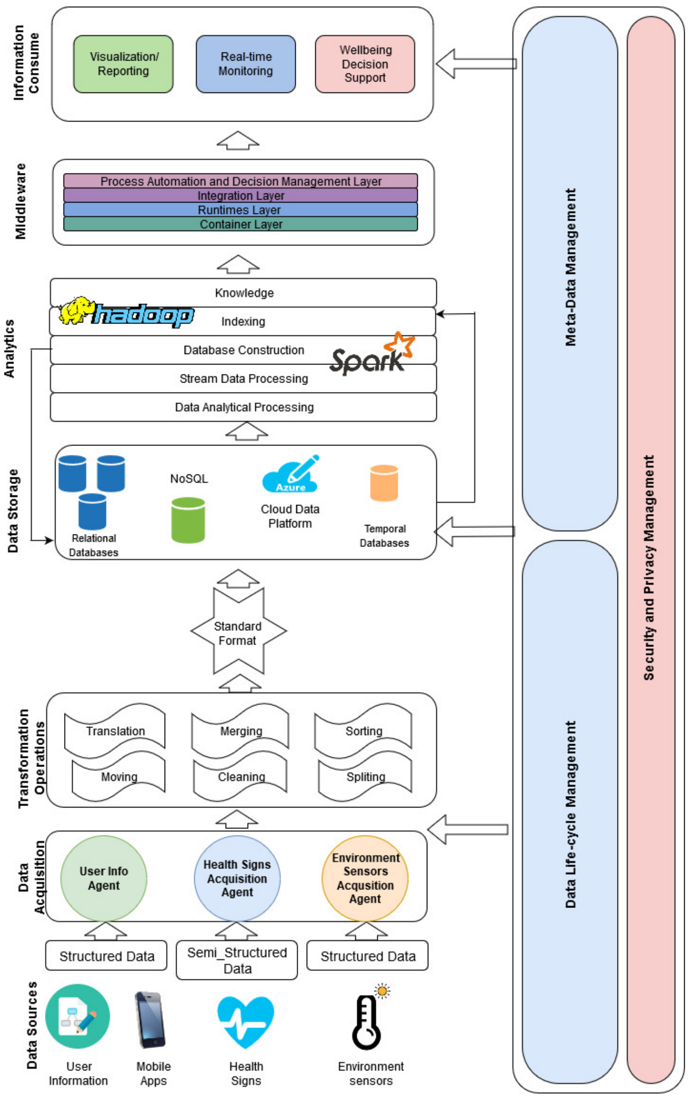

Figure 2. Platform Architecture

3.1.2 Data Acquisition

The process of data acquisition here represented by the **Agents** that are responsible for the data extraction. Data collection could be **automatic** or **manual**.

3.1.3 Transformation Operations

Here operations as **moving**, **cleaning**, **splitting**, **translation**, **merging** and **sorting** are essentials to transform healthcare big data in an standard format.

3.1.4 Data Storage and Analytics

There are a number of different approaches of data systems storage available for facilitating rapid data access. Each of these designs showed in fig. 2 offers different strengths and weaknesses based on the structure of the data stored. Abbreviating the functionality of each of the storage systems that are used in the model. **Relational Databases** were designed for information that's replicated across multiple records, such as a billing database where a single person may have multiple bills. The major advance in big data in the past decade has been the popularization of **NoSQL** big data systems, particularly the *MapReduce* paradigm introduced by *Google*. **Temporal Databases** offer temporal data types and stores information relating to past, present and future this stores data relating to time instances. Data management in the open source Fast Healthcare Interoperability Resource (FHIR) standard is becoming turnkey for interoperability and machine learning on healthcare data. **Hadoop** is the underlying technology that is used in many healthcare analytics platforms. **Spark** is a memory based computing framework which has a better ability of computing and fault tolerance, supports batch, interactive, iterative and flow calculations. The analytic part is focused on basic statistical analysis work. Here occurs the massive healthcare data analytical processing, the streaming data processing, the databases are constructed and optimized, indexing and other analytic operations.

3.1.5 Middleware

Middleware represents the software that provides services and capabilities which are commons to applications external by the operating system. The middleware generally handle the data management, messaging, application services, authentication and API management.

3.1.6 Information Consume

The information consume module is responsible for the reporting/visualization, real-time monitoring and wellbeing decision support.

3.1.7 Data Life-Cycle Management

Lifecycle thinking and lifecycle assessment are scientific methods that support basic policies and data-driven decisions, and inhibit the transfer of problems from one phase of the lifecycle to the next or resolve the problems in one phase to prevent problems from recurring in other phases.

3.1.8 Meta-Data Management

The core goal of metadata management is to simplify the way people and programs find and use data. Metadata gives context, helping to organize and provide relevance to the data itself.

3.1.9 Security and Privacy Management

In healthcare, big data security is vital. Security and privacy policies are essential to control who access the user information and how this information is used. Data protection regulations and high security measures are very important in systems like this.

3.2 Functional Architecture

I used three classic The Open Group Architecture Framework (TOGAF) derived views to better model the system. This division supports a sufficient level of abstraction useful for the model architecture with this level of heterogeneity. This heterogeneity makes this model a typical case of Service Oriented Architecture (SOA) where the architecture must be abstracted from the complexity characteristic-platform of underlying systems (loose coupling principle) [19].

3.2.1 Business View

Describes the model from a computationally independent point of view without technical considerations. The fig. 3 shows the Business View of this model.

3.2.2 Information System

The Information System View provides a blueprint for the individual application systems to be deployed, the interactions between the application systems, and their relationships to the core business processes of the organization with the frameworks for services to be exposed as business functions for integration. The fig. 4 shows the Information View of this model.

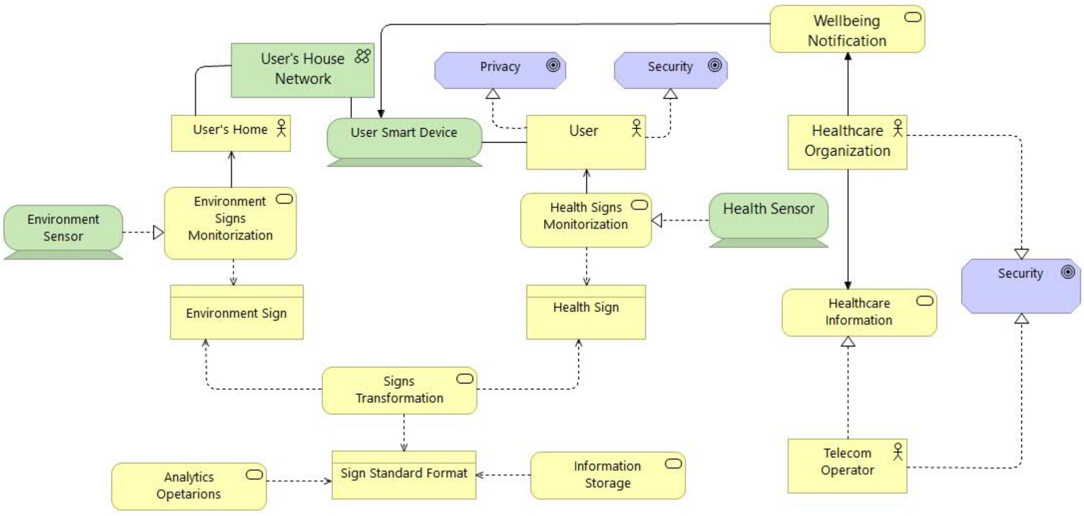

Figure 3. Business View designed with ArchiMate

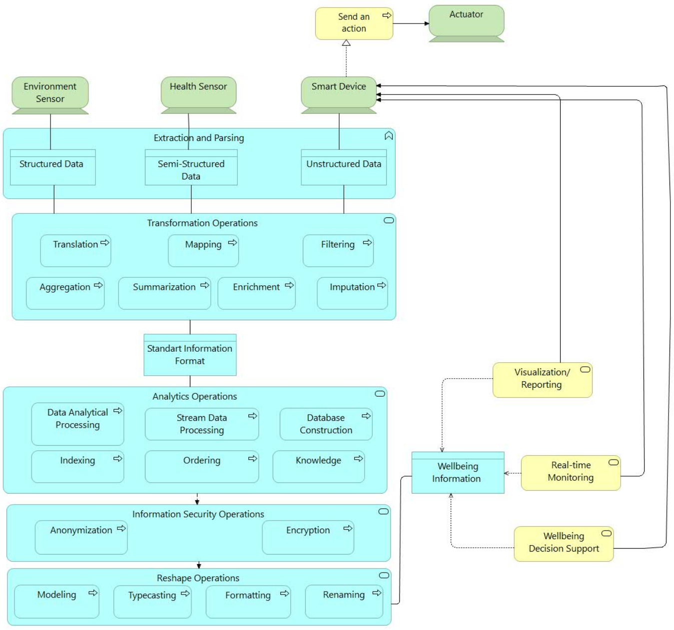

Figure 4. Information View designed with ArchiMate

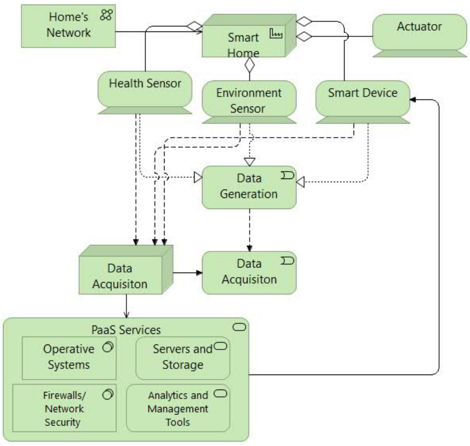

Figure 5. Technology View designed with ArchiMate

3.2.3 *Technology View*

The fig. 5 shows the Technology View of this model.

4 MODEL DEMONSTRATION

In order to better structure my demonstration for the model, I launched a questionnaire on how external factors can affect the individual's well-being. This questionnaire contains the review by Dr. Isabel Botelho, psychologist who reviewed the content and form of the questionnaire and also attested to the real influence of these factors on the individual. The survey was disseminated on social networks until the result of 140 responses. The prevailing set of answers corresponded to users in the age ranges of 14 to 69 years. The answers to the questionnaire made it possible to assess that external factors have a great influence on the individual's well-being.

4.1 Test Environment

In order to analyze the procedure and the complexity with which a model of this type can be installed, I set up a simple test environment.

Where I used the following material:Raspberry Pi 3, Temperature Sensor DHT11, iPhone 11, Apple Watch Series 3, Display, Keyboard and Mouse.

This environment used the DHT11 to measure the environment temperature, the iWatch and the iPhone as connected devices that could be used as sensors and consumer systems. The raspberry was de home automation hub and the home assistant as automation software to be the central home automation control system for controlling smart home technology.

Through this simple test environment I was able to draw some conclusions:

- Through simple hardware and open software it is already possible for a user with some knowledge to build their own intelligent environment;
- Through automations it is possible to create iteration between different devices such as sensors and actuators;
- With the combination of applications it is possible to go further, for example, with an application that reads and interprets the heart rate values of iWatch we can connect to the home assistant and create iterations with other sensors;

4.2 Demonstration Scenarios

4.2.1 Case 1 - User without Pathologies

Maria, 26, lives on the outskirts of the city and is a student worker. Despite not having any health problems, she lives alone and decided to equip her home to provide Assistance to her health and well-being. The system installed in her home provides an environment with a variety of sensors, actuators and interconnected smart devices that work together to make her home a safe place that helps Maria maintain her well-being. These devices allow Maria to be easy to use due to their personalized interfaces and are connected to her contracted operator. This allows, if necessary, remote operation by authorized personnel. As part of the system's infrastructure, Luísa and José's smartphones, herr parents, also interact with her home. Maria uses her smartwatch daily which allows her to see her physical activity and check her heartbeat, she can even do a simple Electrocardiogram (ECG) through it. Maria has always been an anxious young woman and at the time of college exams, under the pressure to manage her professional work and obtain good results in the exams. In order to ensure that her stress levels are kept under control, Maria also uses a sensor daily that measures her stress levels. Her home system is capable of storing both heart rate values and values measured by her stress sensor and interpreting them. And through an algorithm, they combine them in order to provide assistance to Maria. During the afternoon Maria felts a little anxious and the system detected that her heart rate values were higher than usual, so the system sent to her a notification for her smartwatch and smartphone, with an advice saiyng: "Hi Maria, you seem a little anxious, why don't you do some breathing exercises?". Later, the system continues to detect that although the values are not dangerous, they are still slightly altered and notifies Maria again with the following message: "Do you want me to make the house more relaxing?" with Maria's option choosing "Yes" or "No". Maria chooses "Yes" through her smartwatch and the system adapts her home to help Maria stay more relaxed by decreasing the brightness of the house and activating her radio with the playlist that Maria has set to relax.

4.2.2 Case 2 - User with Diabetes Type 2

Leonel, 68, is diabetic and like most adults over 65 have difficulty sleeping. To help he monitor the quality of his sleep, his home system has been fitted with sensors located on Leonel mattress that record his movements, breathing and ECG data during the night. Leonel, woke up at 6 am and the monitor on his Smart TV indicated that his sleep quality index had been 50 percent, a not very nice value. Leonel is also prone to isolation and outbreaks of depression due to his low self-esteem related to his overweight. So his home was equipped with mechanisms and sensors that can constantly measure his cognitive and emotional states. When the system detects an emergency situation, his family and the medical emergency are triggered. Due to his difficulty in getting around, Leonel is followed by his psychotherapist through weekly tele-consults. To remind Leonel of measuring glucose levels in the morning, the system uses the home sound system to warn Leonel through a personalized message with her granddaughter's voice, in order to motivate him for his health: "Good morning Grandfather, are we going to measure your goblins? ". When measuring his levels, on this day, Leonel noticed that they were a little high. After having breakfast, when he went to the living room, he started to feel a strong pain in his heart and his smartwatch detects that he is having a heart attack. His home system automatically triggers the medical emergency and his family while his system instructs he to do a cardiac massage.

4.2.3 Case 3 - User in a Hospital Environment

The 10-year-old Salvador, today, goes with his parents to the downtown health center to get the tetanus vaccine. The Salvador is always a little nervous when he goes to the vaccines and before entering the office he is usually already crying. But the health center installed in its pediatric office a system with smart lamps with different colors, and relaxing aroma releasers that include an actuator. In addition, the children, before entering for each consultation, receive an electronic bracelet that is personalized at the moment with the information of their favorite color and favorite cartoons. The Salvador received his bracelet that contained the information that his favorite color is orange and that Mickey Mouse is his favorite cartoon. Upon entering the office with his bracelet, the Monitor started an episode with Mickey, the lamps changed their color to orange and a lavender scent was felt in the air. The Salvador quickly forgot that he was going to take a vaccine and kept his attention on Mickey and the orange lights, while the lavender scent made him relax and without realizing it, he took the vaccine without crying.

5 Evaluation

Analyzing the three use cases we can conclude that the following requirements are met:

- **Data Generation:**the three use cases use different types of sensors that are responsible for the generation of data that feed the system.
- **Processing and Storage:**the system shows the ability to store information and to process it when it is able to interpret and combine the data it receives.
- **Consumer subsystem:**the consumer subsystem is represented in use cases in different ways. In the first case, through notifications and certified health application and in the second case, the user receives consultations through the system.
- **Device manager:**the function of the device manager is demonstrated through the way sensors and actuators are activated in order to take the necessary actions.
- **Appropriate Access Control Policies:**in the first use cases, we can see that only authorized users, authorized family members and authorized health identities have access to the users' systems. In the third use case, the system is fully controlled by the hospital.
- **Notification Service:**in the first use case, we can see the notification service working in full, when the user is notified with an advice.
- **Performance subsystem:**the functionality of the performance subsystem is demonstrated through the selection of devices that are connected to the system network, such as the wi-fi radio or the consulting room display.

5.1 Model's Limitations

The model may be limited in it's non-functional requirements that can be strongly interconnected with the hardware and software chosen for each solution. One problem could be the integration of different devices from different manufacturers or using different types of protocols but the solutions with this model as a basis foresee the creation of adapters that allow to overcome this type of situations.

6 Conclusion

To conduct this research, I followed the DSRM methodology, which consist of 6 phases of development. After you have gone through all the phases and especially the model evaluation I could conclude that this model as the follow advantages: Some of the advantages of the model, are:

- It can be completely adapted to the needs of each user;
- It can help people with chronic illnesses and also people who are concerned with maintaining their well-being;
- It has the ability to help the physical and psychological well-being of the user, showing to be a holistic model;
- It is scalable and can integrate a wide variety of devices and software;
- It is reliable because regardless of the solutions it is based on the connection to a health structure;
- It is an asset for the burden of health systems, caregivers and family members;
- Introduces a proactive health concept that allows users to start taking care of their health as soon as possible;
- It is an asset in pandemic situations as it allows the control of patients infected with mild symptoms with medical support at a distance, thus protecting patients and health professionals.

Regarding the outcome of this thesis work, there are several research opportunities that can be addressed for future work:

- Develop a real prototype of this model in partnership with hospital networks;
- Collect more opinions and suggestions from health professionals and users to reformulate the model with more options;
- Do a job with several companies that can be involved in a model like this to look at the market;
- Develop an in-depth search of who could commercialize this type of product as a whole to the end user.

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