Development of an IoT Network for Elderly Healthcare

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Bachelor's thesis in Energy Technology

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Abstract

The thesis was commissioned by the Novia University of Applied Sciences to create an IoT smart network that demonstrates the potential of technological solutions in the elderly healthcare home.

The different aspects studied were the main challenges the elderly have at their home and, afterwards, the role IoT has in the healthcare domain. Finally, a smart home to assist the elderly's life was designed based on the simulation room for training nurses located in the Alere building.

The project consists of the development of an IoT network consisting of four devices (door sensor, pressure sensor, weight sensor, and smart pillbox) which are communicating with a Raspberry Pi through MQTT to collect data and analyse it in Node-RED. The dashboard of Node-RED allows to have an interface for the medical professionals to see the status of the elderly and sent an alert if there is an anomaly.

Future work is suggested and is related to further testing of the IoT network into the simulation room and making the network more comprehensive with the incorporation of more sensors.

Language: English

Key words: Internet of Things (IoT), Elderly Healthcare, Node-RED, Message Queuing Telemetry Transportation (MQTT).

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1 Introduction

The Organisation for Economic Co-operation and Development (OECD, 2021) define an elderly population as those individuals aged 65 and over. The number of elderly people is increasing as a proportion of populations in most developed countries around the world (World Health Organization , 2018).

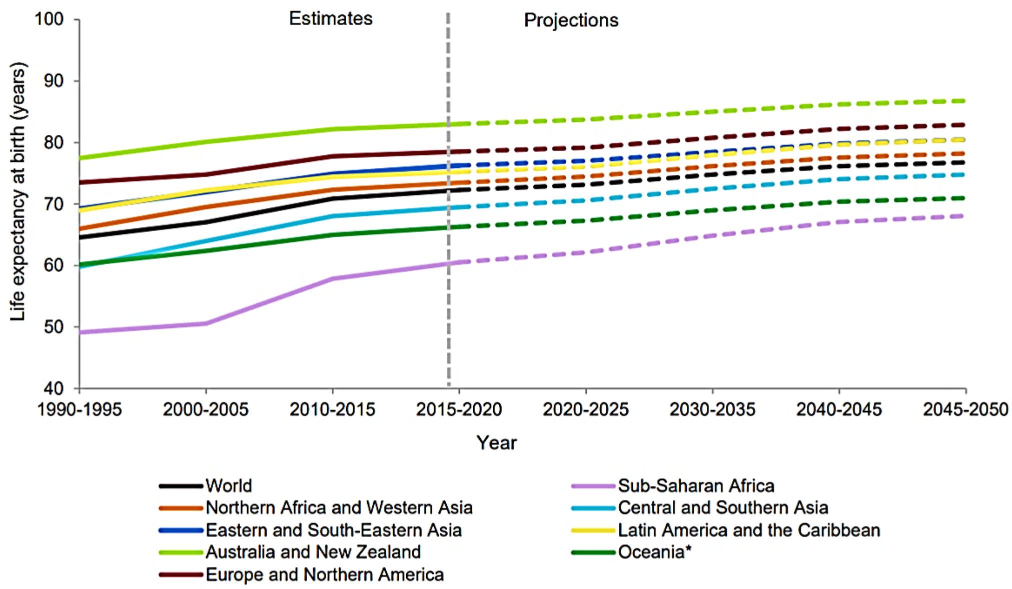

Figure 1. Life expectation by region, 1990-2050 (United Nations, 2019).

As shown in Figure 1 the life expectancy is increasing all over the world, this is a synonym for the increase of the elderly population. For example, the world life expectancy was about 65 years old in 1990, while in 2019 was more than 70 years old and it is predicted that in 2050 will be about 74 years old. The National Institutes of Health (2016) estimate that between 2015 and 2050 the proportion of the world's population over 65 years old will be nearly double from 8.5% to 17%, which means by 2050 is expected to be 1.6 billion elderly. Moreover, this will put an increasing burden on improving health care support in order to give a better life quality to all elderly and their families.

It is estimated that the healthcare expenditure (HE), the total amount of money spent per year on health goods and services, for the population aged 65 or over is the most significant one compared with the other age groups with an HE per capita of 303.04 € (Li, et al., 2020).

This, in a long term, is financially not a sustainable statistic that needs to be controlled to not convert it into an economic crisis. For it, the government should not only work on the supply side such as reforming medical insurances payment and developing new technologies but also focusing on the demand side, such as intensifying healthcare quality, reducing environmental pollution, and improving the health of elderly people.

One of the most challenging and sometimes inevitable changes in aging is the loss of autonomy in daily life activities. For example, it has been demonstrated that paid care services, such as residences for the elderly or nursing home, can cause depression, social isolation, and greater dependency in the development of self-care tasks (Mattimore, et al., 1997). Accordingly, most elderly people often prefer to stay in their homes rather than enter a healthcare institution (NIH, 2017). Nonetheless, sometimes the entrance to a nursing home that provides 24-hours assistance is needed to some residents with age-related illnesses such as dementia or osteoporosis.

Taking this into account, it is essential to develop and implement new strategies and technologies in order to provide better health care ensuring maxim comfort, independence, and participation among older people. Between their own homes and the nursing homes are different steps to take, one of them is Assisted Living homes, with facilities based on supporting residents to maintain a safe environment with a high degree of autonomy, however, it still demands the elderly to leave their own home (Elizz, 2019). For this reason, the Internet of Things is trying to find a new solution monitoring the elderly's houses to make them safer.

The Internet of Things (IoT) focused on digital medical devices makes it possible for the elderly to monitor home health. This technology allows to set up IoT network based on home care to monitor the elderly's status to detect anomalies and get services in those cases. With this monitorization, the elderly will be able to live longer in their own home with no need to go to healthcare institutions.

1.1 Aim and objectives

This work was commissioned by Novia University of Applied Sciences and specifically the Nurse Training Programme. A simulation room was created in the Alere building to replicate the challenges the elderly may have regarding health care provision.

The aim of this thesis is to facilitate and improve the lifestyle of elderly people by integrating different sensors in the simulation room. This allows for interpreting the environment and sends the information to the medical centre to identify, as soon as possible, if there is an anomaly.

The objectives of the thesis are:

- Identify the challenges the elderly have in their daily life.
- Document the status of IoT technology in healthcare.
- Develop an IoT network to monitor elderly healthcare in their own home.

1.2 Disposition

The thesis begins with an introduction of the subject and the reason for what it is needed to be developed. Thereafter comes the theoretical chapter (Chapter 2) where the concepts and theories used for identifying the challenges are presented and the facilities the IoT gives to solve some of them. Following that, Chapter 3, is the practical framework where the IoT network is developed, and the sensors are explained. The last two parts are the test and results obtained through the Node-RED tool and the discussion of them contrasted with the objectives (Chapter 4 and 5). Lastly, in Chapter 6, the conclusion is presented where the findings are summarised and opportunities for future research suggested.

2 Theoretical background

In this section, the main concepts and ideas of the thesis are explained. The main challenges of the elderly in their homes, the simulation room where the practical background will be developed, and the IoT technologies in the healthcare domain.

2.1 Main challenges of elderly in their homes

Aging involves loss of autonomy in daily living activities causing a range of different challenges to elderly people. However, living in their own homes gives them a sense of familiarity and comfort that is lacking in other places where they can live.

The free radical theory of aging asserts that many of the changes that occur in our bodies with aging are caused by free radicals, unstable oxygen molecules that cause proteins and other essential molecules to not function as they should (Harman, 1992). Another theory is based on the immune and endocrine systems deterioration with age that gives rise to several infections resulting in disease (Cardinali, et al., 2008). The last theory was developed by Troen (2003) and is based on the DNA and genetic theory, our cells can only divide so many times to produce new cells before some DNA is lost, which eventually results in cell death. As a consequence of all these changes, the elderly are at a much higher risk to develop disabilities and chronic illness that require medical care (Lovell, 2006).

Psychreg (2020) classify the main elderly's challenges in emotional challenges that lead to loneliness and chronic illnesses; physical challenges, because of the edge, the bones become brittle, and this make elderlies fall while attending to routine tasks and they are unable to stand up and seek help; mental challenges as dementia or feelings of fatigue that can cause over or underdose, a fire, or waste of electricity and water; and poor nutrition challenge causing big changes on the weight.

There are many emotional effects of aging, and many of them are positive because they are more focused on the good things in life, and they are emotionally more stable. Nonetheless, some of the effects are also challenges for them. Elderly people are more vulnerable, and they are aware of it, and this makes them feel more anxious about their safety. Moreover, retirement can sometimes be a recipe for boredom, loneliness, and depression (Gumaer, 2019). The statics of the Centers for Disease Control and Prevention (2021) shows that depression affects between 1 and 5% of the general elderly population, however, when talking about elderly who need home healthcare, the percentage increase to 13.5%.

Physical challenges are the most common and known challenges for the elderly. Falls are the number one cause of fatal and nonfatal injuries among adults aged 65 and older (CDC, 2020). Falls can cause broken bones and hip fractures with a very long recuperation for elderlies, head injuries with serious problems, especially if the person is taking certain medicines like blood thinners and can cause apprehension of falling again even if they did not get injured, this fear can cause a person to cut down their everyday activities. Moreover, according to data collected by the National Health Interview Survey (2013) 60% of the fall accidents in the elderly happened inside the house.

However, there are other changes that the elderly undergo that can end also as a challenge for them: decrease taste and smell, decrease vision and hearing, increase fat percentage, loss of bone mass, increase predominance of cardiovascular disease, loss of muscle control, strength, and endurance, and decrease liver and kidney functions (Lovell, 2006).

Mental health disorders are doubtless caused by several factors which interact in late life. Alzheimer's disease is the most common cause of progressive dementia in older adults, but there are other causes as damage to the vessels that supply blood to the brain (vascular dementia), Lewy Bodies dementia and Frontotemporal dementia (Wang, et al., 2016). All these types of dementia are progressive and irreversible. According to Mayo Clinic (2019) based on their studies establish that the main symptoms of this problem are the loss of memory, the difficulty of communication, the difficulty in reasoning or handling complex tasks, and disorientation.

The three challenges exposed before can trigger a nutritional complication, some of the emotional issues or the physical limitation can difficult the elderly not be motivated to go shopping or cooking, and dementia or other mental challenges have some cognitive changes as expose before that can difficult some daily tasks as cooking. Nutritional problems can cause several complications in the immune system, in the energy levels or chronic health such as type 2 diabetes or high blood pressure. For this reason, it is important elderly do not make big changes in their diet and try to keep constant caloric ingestion and weight (Nowson, 2007). The elderly have reduced metabolism, so they burn fewer calories than younger people, and they have reduced activity. Both things can lead to obesity. On the other hand, also limited access, a decrease of the appetite or difficulty in cooking can cause weight loss. In conclusion, Gaddey and Kathryn (2021) in their studies assert that unintentional weight loss or gain in more than 5% is a reason to visit a medical expert.

2.2 Simulation room

The Novia University of Applied Sciences have a well establish Nurse training course, more information about the bachelor's degree can be found in the following link.

https://novia.fi/study-at-novia

One of the crucial parts of the curriculum is the elderly care support, to facilitate this training a simulation room has been created to analyse the different challenges in a typical home environment. The simulation room is located in the Alere building (Wolffskavägen 31, Vaasa), the main entrance of the building is shown in Figure 2.

Figure 2. Alere building main entrance.

The simulation room can be found on the second floor, room A268. Figure 3 illustrates the different furniture in the room. It is composed of an individual bed with a bedside table; a kitchenette with a fridge, a sink, some cupboards, two electric cooking plates, and a paper dispenser; a table with two chairs; and a living room with two armchairs, one small table, a sideboard with a television, a lamp, and a rug. However, the room does not offer a bathroom, one of the most dangerous parts of a home.

Figure 3. Different photos of the furniture in the simulation room.

The simulation room is usually used for teachers and students to rehearse scenes of daily life and analyse the behaviour. Nowadays the room has lots of facilities to install technological devices, the goal of the room is to create an IoT healthcare network with numerous sensors to improve the elderly's living conditions.

2.3 Internet of things

The phrase "Internet of Things (IoT)" was first introduced in 1999 by Kevin Ashton to describe a network of physical devices connected to the internet in order to communicate and share data with each other (Ashton, 2009). But since sensors play such an important role in this concept, IoT can also be described as a sensor network. The goal of IoT is to use the large amount of data collected by the sensors to make systems more efficient and automated (Quin, et al., 2015).

One of the main challenges of developing the Internet of Things is the standardization of IoT protocol layers. An IoT technology is usually built upon a three-layer structure: the application layer, the network layer, and the device layer (HaddadPajouh, et al., 2020). The application layer consists of the IoT hardware such as sensors and actuators that can be modified or newly integrated to manage and operate the functionality of the physical device. At the network layer, communication protocols such as MQTT enable communication between the devices and the cloud. Finally, the device layer allows the device communication and management software, and the possibility of store, process and analyse the data generated by the devices (Wortmann & Flüchter, 2015).

2.3.1 IoT transport protocol

To send data between devices via WiFi on the Internet of Things, a transport protocol is needed. The most popular transportation protocol is Message Queuing Telemetry Transportation (MQTT), which is based on the publish/subscribe network protocol between IoT devices as can be seen in Figure 4. System configuration using MQTTFigure 4 (Soni & Ashwin, 2017).

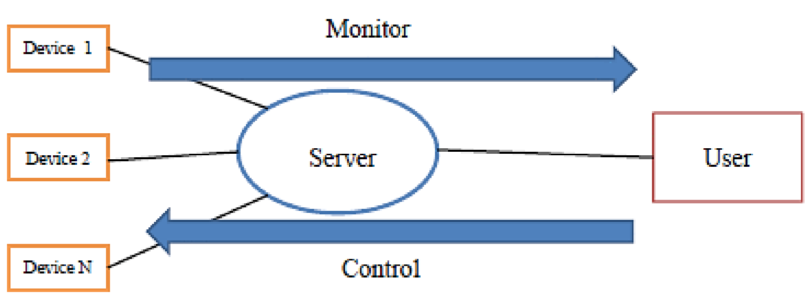

Figure 4. System configuration using MQTT (Yokotani & Sasaki, 2016).

MQTT is an open-sourced protocol for passing messages between multiple clients through a central broker. The most advantages this protocol has is the lightweight and efficiency that allows small microcontrollers to use it, it has bi-directional communication allowing messages between the device to cloud and cloud to device, it is able to connect with millions of IoT devices, it has a reliable message delivery with the opportunity of defining three different levels (0-at most once, 1-at least one, 2-exactly once), it needs low time to reconnect the client with the broker, and it is easy to encrypt messages using TLS to ensure security (MQTT, 2020).

However, Hyper Text Transfer Protocol (HTTP) is the historical protocol used to transfer data on the World Wide Web and therefore it is natural that it is also used for IoT applications. Its mode of operation is based on the type of request/response, which means that the client makes the request and waits for the server to process and re-establish the connection for the response (IoT Consulting, 2019).

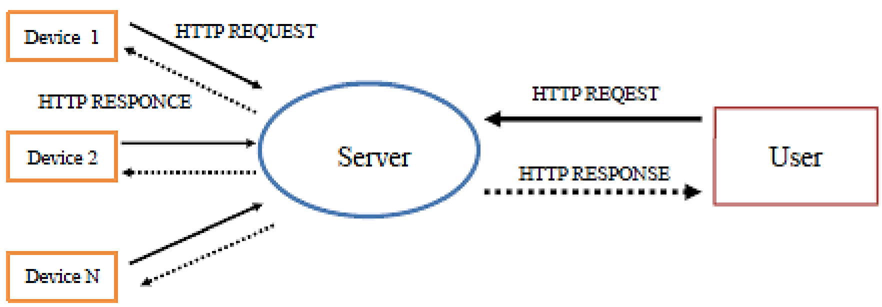

Figure 5. System configuration using HTTP (Yokotani & Sasaki, 2016).

Figure 5 illustrates how the communication is done between the devices and the user. It is a one-to-one communication based on the HTTP methods GET to obtain data, PUT to send data, POST to create a resource, and DELETE to delete it. This method allows to send and receive a big amount of data, but with a larger message size than MQTT, due to the use of non-binary text formatting.

2.3.2 Internet of things in healthcare

The number of applications and services IoT can provide is almost unlimited and can be adapted to many fields of human activity, facilitating, and improving their quality of life in multiple ways (Salazar & Silvestre, 2010). Atzorin, et al. (2010) classify the applications in 4 different environments:

- Transportation and logistics domain based on the real-time monitoring of the supply chain, being the transportation the most important part. Transportation is progressing to assisted cars to allow better navigation and safety.

- Healthcare domain includes both real-time position tracking, such as patient flow monitoring to improve workflow in medical centers and tracking of motion through congest points. Also is working with the collection of real-time data to create automated care through sensors to diagnose patient conditions constantly.

- Smart environment domain refers to making comfortable homes and offices in several aspects like room heating, room lighting, optimization of the power consumption, among others.

- Personal and social domain applications are those that enable the user to interact with other people through social networking, historical queries about objects and event data, and search of lost things.

Furthermore, IoT Analytics (2020) classifies the applications in 10 different areas and analyses the paper of each one. The number one application is the Manufacturing and Industrial area, followed by the Transportation area and the smart Energy solutions as Figure 6 illustrates.

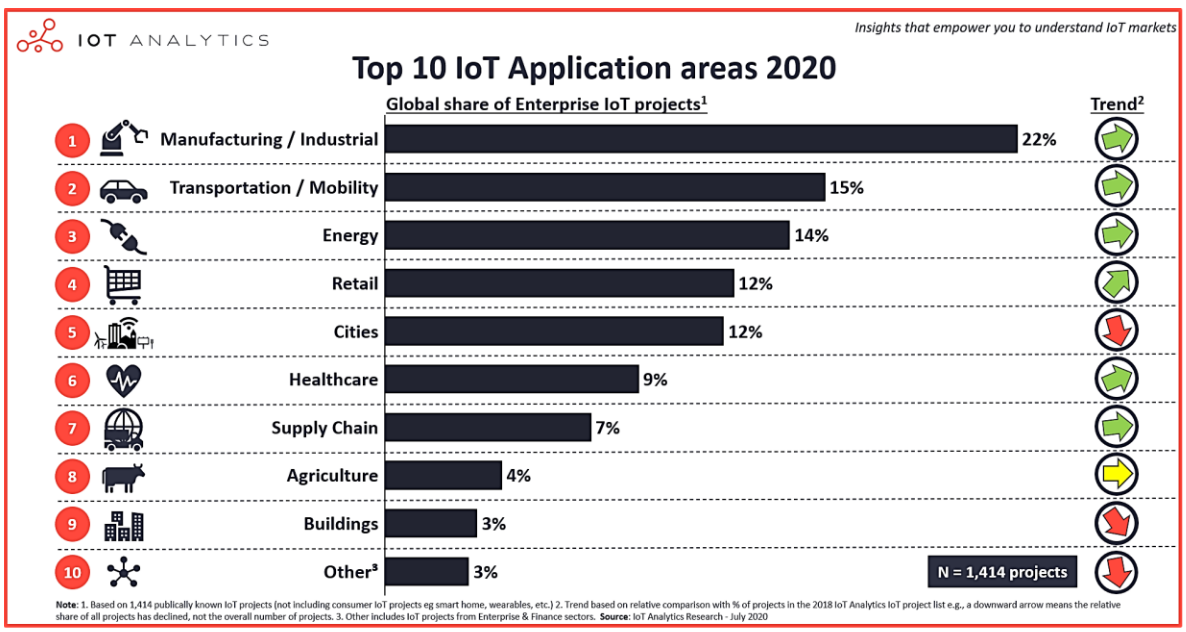

Figure 6. Top 10 IoT Applications areas 2020 (IoT Analytics, 2020).

Focusing on the healthcare domain, it is seen that is the sixth-largest application area with rapid development in recent years. It is based on the Internet of Medical Things (IoMT), this market is predicted to exceed 8 billion euros by 2024 and revolutionize the healthcare industry (Brand Essence, 2015). The main objective of IoMT is to sense and upload up-to-date patient information to the cloud in emergencies. Figure 6 shows that it is increasing considerately due to the COVID-19 pandemic. However, Phadnis (2020) said: "These solutions are here to stay even after the current crisis". This is a clear sign that the pandemic has thrust the healthcare industry and applications such as telemedicine, remote patient monitoring, and interactive medicine are expected to gain importance during this time.

The IoMT has several different applications, Al-Turjman, et al (2020) classify them based on being body-centric or object-centric and their environment, as illustrated in Figure 7.

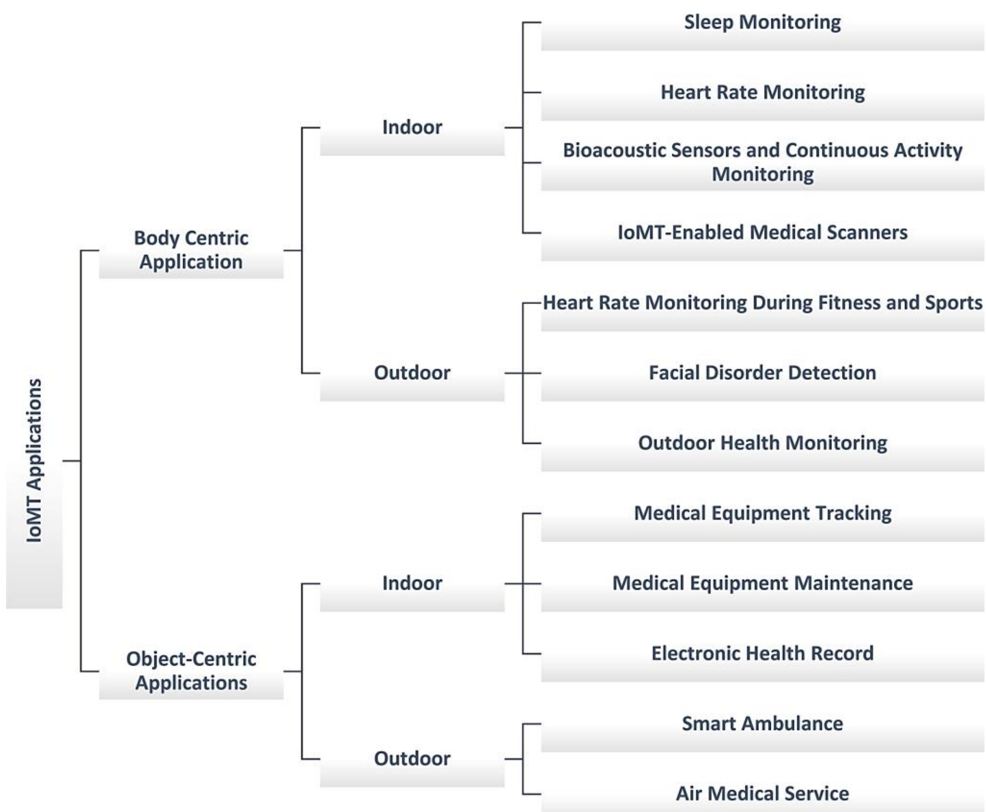

Figure 7. IoMT application classification (Al-Turjman, et al., 2020).

Body-centric applications are once referring to healthcare devices that generate psychological data directly interacting with the body and sending the data to the medical professionals. These devices can be wearable or non-wearable, the first ones are smart devices like implants or accessories while non-wearables are the ones that are not worn on the human body, for example, weight sensors.

Object centric applications are not directly related to the human body, is referring to healthcare solutions and services that can be efficiently used to improve healthcare delivery. The best example is hospital management systems, including tracking of medical equipment, smart ambulances, among others.

Moreover, Dr Vinita Kamani (2020) distinguishes the IoMT devices into seven categories: fitness wearables, clinical-grade wearables, remote patient monitoring devices, smart pills, point of care devices and kiosk, clinical monitors, and hospital devices. This classification is like the Al-Turjman, even if it is not saying body-centric or not, and indoor or outdoor, the different categories can be part of a ramification in Figure 7.

Besides that, Cosgrove (2018) distinguish three potential IoMT applications: remote patient care, hospital operations, and data management. Remote patient care refers to set up remote equipment to measure biometrics allowing the doctor to receive data and modify the care plans of the elderly. Hospital operations are based on optimization of hospital daily functions tracking medical assets by attaching sensors to the equipment. Data management refers to the necessity of analysing and proceed the data to be useful for medical professionals.

3 Practical framework

In this chapter the different sensors and the way to interconnect them to reduce the challenges elderly can have in their own home will be exposed. The psychological issues cannot be avoided by means of IoT; however, the other three challenges can be avoided, or damage reduced, making them not crucial, with the interconnection of several sensors.

3.1 Sensor network structure

The sensor network for this project will consist of 4 different sensors connected each one to an ESP32 that, through WiFi, will send the information to the Raspberry Pi that collects all the data through the Node-RED to, later on, analyse it and send alerts to the medical centre.

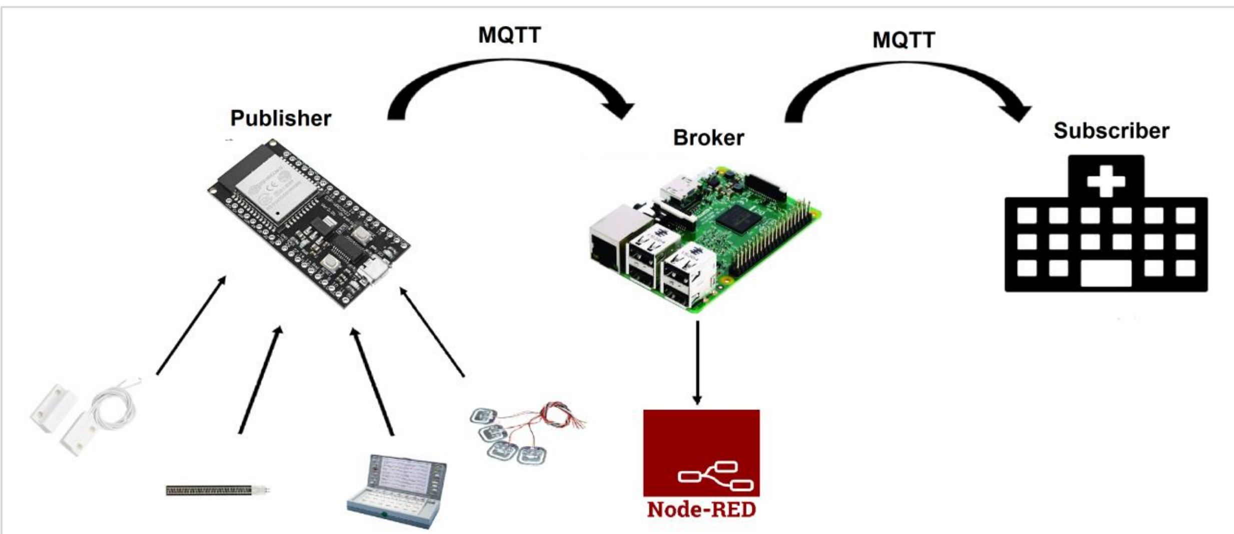

Figure 8. Diagram of the sensor network.

The ESP32 is a low-cost and ultra-low power consumption microcontroller with WiFi (2,4 GHz band) and Bluetooth 4.2 capabilities. The device is the heart of the project as is used to connect and program all the sensors. The ESP32 operating voltage range is 2.2V to 3.6V, it is highly integrated with amplifiers, filters, power management modules, and wearable electronics that make it possible to build an Internet of Things applications (Kurniawan, 2019). Further information on the device is detailed in Appendix 1.

The ESP32 program is written with C programming language, and there is the option to use the Arduino ID as the programming platform. The ESP32 kit used in the project is ESP32-WROOM-32D. The Pin description about how the ESP32 has to be connected with other devices can be found in Appendix 2.

The Raspberry Pi is a small, powerful, and cheap computer board able to interact with the outside world using sensors and cameras. The operating system of the device is Linux, and the programming language is Python. In this project, the Raspberry works as the bridge between the ESP32 and the end users. The Raspberry is connected to the Node-RED, a programming tool to create applications by dragging nodes from a customizable palette into a workspace and wire them together. The programming language is JavaScript and the flows created are stored using JSON (NodeRed, 2021). The Node-RED structure to interconnect all the data will be explained and developed further in Chapter 4.2.

For the purposes of this project, four devices were indicated by the sponsors as have the greatest need for the simulation room training resource. All the devices are non-wearable body-centric applications (following the classification of Figure 7) because are the ones that do not need the elderly to think and carry them all day long.

1. Main door sensor

2. Pressure sensor for the bed and armchair

3. Weight sensor

4. Smart Pillbox

These sensors were selected considering the cost of each device (as low as possible to make the smart medical care accessible for everyone), the precision and accuracy (inaccurate data may be misleading and could be harmful to the patients), it is imperative to ensure the security and privacy of the data, all the devices need to be maintained properly to avoid some electrical problems, and the main goal is to make like easy and make the devices usable.

The main goal was to try to detect the different types of problems the elderly may have. For this reason, the election of the sensors had to cover physical, mental and nutritional. One of the most common problems, explained in more detail in Chapter 2.1, is the elderly falling while performing daily tasks without being able to stand up to ask for help. To mitigate this problem there are several solutions like avoiding objects around the room, adapt the stairs, use proper illumination, among others. It is important to detect if the elderly fall, as soon as possible, and this was the first objective of the IoT network.

Different ideas were exposed, for example, a camera. The idea of the camera was to be able to detect the position of a person (stand up or lay down) and the change from one to the other. Nonetheless, this option was recording the elderly and therefore it was difficult to guarantee their safety. In addition, it can be a challenge to convince the elderly due to their insecurities about technology. Floor sensors capable of detecting falls were also considered, but this option was more expensive as it was necessary to install several sensors all over the floor with major renovations in the room. Finally, the option of focusing on falls during the night was considered the most appropriate because this is the time when the person is most physically weakened, and the illumination is worst. The best solution found was to install different pressure sensors on the bed and armchair to detect if during the night the elderly person got up and did not return to them.

Focusing now on mental problems, one of the most dangerous problems would be to leave the house during the night sleepwalking or due to dementia without knowing how to get back to it. That is why the sensor on the door to detect if it is opened during the night is one of the most efficient solutions for this. Another mental problem with serious repercussions is related to medication, hence the possibility of developing a smart pill dispenser. Developing it from scratch was very complicated and unreliable, so the decision to buy one developed by a professional team with WiFi to be integrated into the IoT network with the other sensors was the most optimal solution.

Finally, the last challenge is related to nutrition, for which different ideas were put forward, such as the possibility of installing a sensor for the fridge door to detect how many times it is opened, or a temperature sensor to know if the cooker, oven, or microwave are used for cooking. But finally, the most direct method to know if the nutrition is correct or not is to know the person's weight and see if it increases or decreases considerably. For this reason, a weight sensor next to the bed was the best solution found, to weigh the elderly person every day without the need for them to do it themselves. In the future, this solution can be combined with the previously mentioned ideas, fridge door sensors, stove temperature sensors and others.

Figure 3 is the plan of the room where the 4 sensors exposed before will be installed. Moreover, other sensors are going to be installed in the room by the EPS students before the end of this academic year to increase the IoT network.

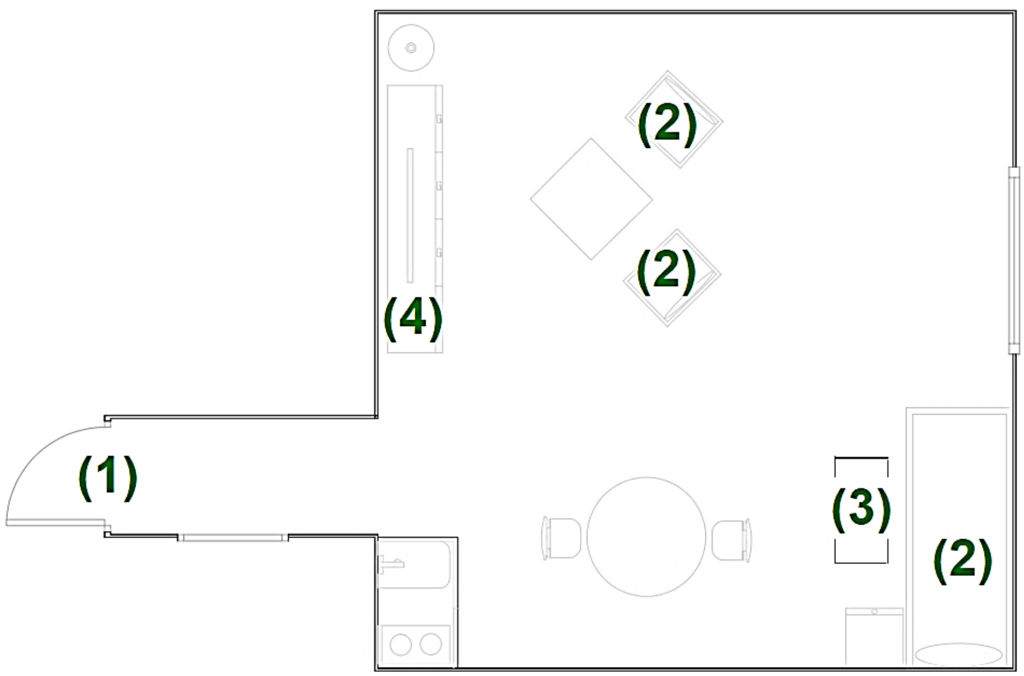

Figure 9. Plan of the simulation room in Alere.

The four different sensors of the project are door sensor (1), pressure sensor (2), weight sensor (3), and smart pillbox (4). They are located as shown in Figure 9**¡Error! No se encuentra el origen de la referencia.** and represented with each number. With them, several incidents and challenges can be detected remotely and allow the medical staff to act faster. The equipment setup with full documentation can be found in Appendix 1.

3.2 Door sensor

The door sensor is the first sensor developed. It is shaped of two different components: the reed switch with two pins and the magnet. The magnet is attached to the door and the reed switch, next to the door frame. When the door is closed, the two components are in contact and the circuit is closed (input pin is LOW). Nevertheless, when the door is opened, the two components will separate causing an open circuit (input pin is HIGH). The hardware connection of the sensor can be found in Figure 10.

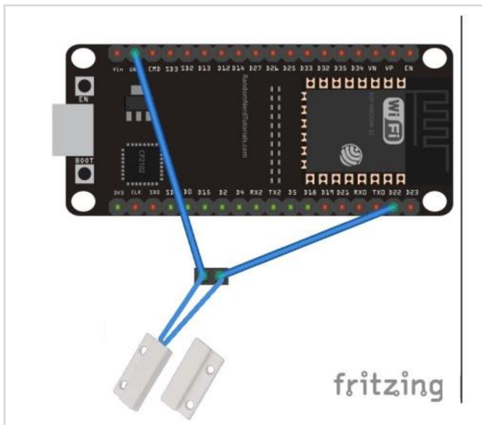

Figure 10. Hardware connection door sensor.

The connection of the sensor is quite simple, just need to connect one of the pins to the ground and the other to a digital input, the selected one is pin 22. Moreover, the software of the sensor is detailed on the flow chart in Figure 11 and can be found in the OneDrive folder of the project, the C program will detect the current state and compare it to the previous one, if it is different, the MQTT will be connected, and the changing state will be sent to the broker (MQTT topic home/doorsensor).

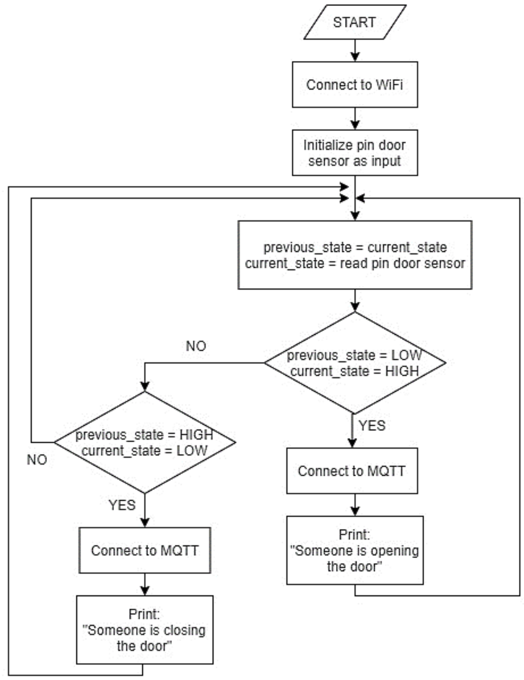

Figure 11. Flow Chart diagram of door sensor.

Door sensors are used to detect if someone is opening or closing the door, it is an essential component of home security. Moreover, in the healthcare environment is also very useful, for example, to know if the elderly have forgotten the door opened or has left the home in an unusual hour, maybe acting without being conscious and forgetting how to go back home.

Figure 12. Assembly of the door sensor into the author's room.

The door sensor is attached to the room as illustrated in Figure 12. The sensor is programmed to be attached to the main door, however, as can be seen in the photo, it was attached to the author's room door because it was the easiest way to check the status and its proper functionality.

3.3 Pressure sensor

Pressure sensors can be categorized into three main measurement modes: absolute, gauge and differential. In this project the proposed pressure sensor's function is based on the properties of the sensor strain gauge, the working principle rests on the piezoresistive effect. The core material of the sensor is a crystal that has the property of generating an electrical charge on the mechanical stress. The generated charge is thereby proportional to the applied force or pressure.

The sensor used in the project is flexible, ultra-thin (0.35mm), highly sensitive and long service life. The test voltage is typically DC 3.3V, the response time is less than 10ms and the working temperature range is -20 to 60ºC.

The project has one sensor of 600mm installed on the bed to detect the pressure exerted on it, and one sensor of 150mm installed on the armchair working with the same principle. This will allow detecting if in the middle of the night someone wakes up from the bed and does not come back to it. This will alert the medical professional, as it is an anomaly that maybe means that the elderly has felt on the floor or has some other issue.

The hardware with the connections of the sensor can be found in Figure 13. One of the pins of the sensor is connected to 3.3V, while the other one is connected to pin 31, pin function ADC1 (it is important not to use the ADC2 pin because is the one used for the WiFi) and to a resistor of 2.2kΩ that goes to the ground.

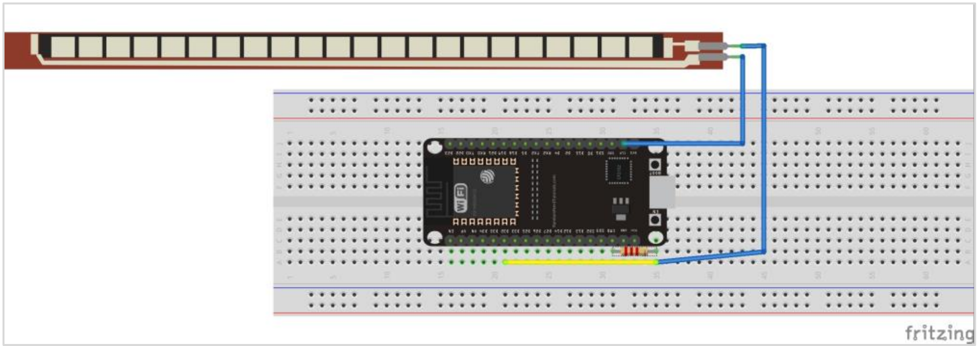

Figure 13. Hardware connections pressure sensor.

It is indispensable to use the resistor to create a voltage divider between the 3.3V and the ground. One of the resistors of the divider is 2.2kΩ and the other one is the potentiometer given by the pressure sensor. Using the voltage divider, the device will be able to see the change in the voltage and convert it into exerting pressure.

Moreover, in Figure 14 the flow chart of how the pressure sensor works is exposed.

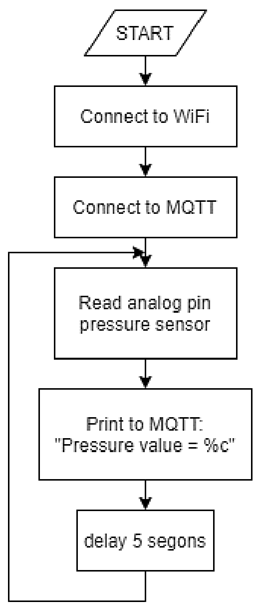

Figure 14. Flow Chart diagram of the pressure sensor.

The pressure sensor is reading the pressure value of the analogue pin, and it is sent to the MQTT broker with the topic home/bedpressure for the data of the bed sensor and home/armchair for the data of the armchair. This data is analysed later using the Node-RED as is explained in Chapter 4.2.

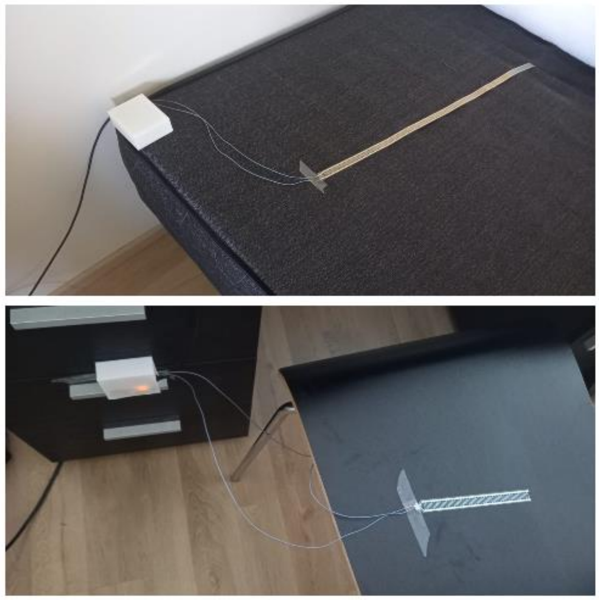

Figure 15. Assembly of the pressure sensors into the author's room.

Figure 15 illustrates the two pressure sensors used in the project, the above one is attached on the mattress down the bedsheets to detect when someone is on the bed, because of its thickness, it is not perceptible and therefore unobtrusive. The bottom sensor is the one that should be attached to the armchair, however, in the author's apartment, it is attached to the chair.

3.4 Weight sensor

The weight sensor, also called load cell, is known for its accuracy and consistency in delivering exact weight values and hence these sensors can be used in designing a weighing system. A load cell is a force gauge that consists of a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured.

The project uses a strain gauge load cell as it is the most common one in industrial applications, is it ideal as it is highly accurate, versatile, and cost-effective. To be able to measure until 200Kg, it is using four load cells of 50Kg each one connected in a Wheatstone bridge configuration. It also needs an amplifier module HX711, the voltage change in the load cell is too small and the Arduino cannot appreciate it.

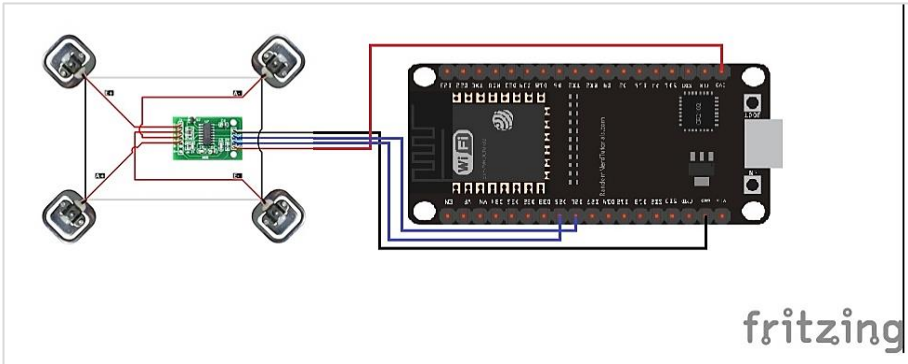

Figure 16. Connection of weight sensor.

Figure 16 illustrates the way the 4 load cells are connected to each other and with the amplifier. Later, the 4 outputs of the HX711 are connected to each pin on the ESP32, the GND and VCC of the amplifier and ESP32 together, and the other two pins (DT and SCK) to digital IO pins (pins 32 and 33, respectively).

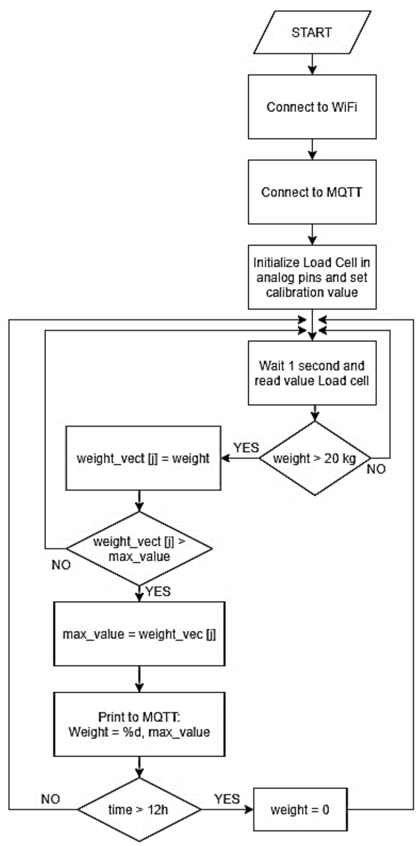

Figure 17. Flow chart diagram of weight sensor.

The C++ program of this sensor is based on the flow chart of Figure 17. First, the connection of the ESP32 via WiFi and the MQTT is done, as well as the initialisation of the Load Cell via the two pins (dout and sck). Furthermore, the calibration value is defined (previously this value is calculated by the calibration function of the HX711_ADC library). Then we start the loop where every 1 second the new sensor value is read, and the maximum value is stored in a variable. This value is sent by means of the MQTT to the Raspberry to be able to make the graph of the weight as it is explained in Chapter 4.2. The maximum value is also reset every 12 hours. The program taking the maximum value was the simplest way to detect the elderly's weight, however, it may trigger ambiguous data if, for example, the elderly person is carrying something.

To create the device, the 4 strain gauges are attached to a piece of wood used as a standing surface to measure the weight. To attach the sensors to the wood, 4 enclosures have been printed using 3D. The result of the device can be seen in the following picture. Moreover, the enclosures designs can be found in the OneDrive folder of Appendix 3.

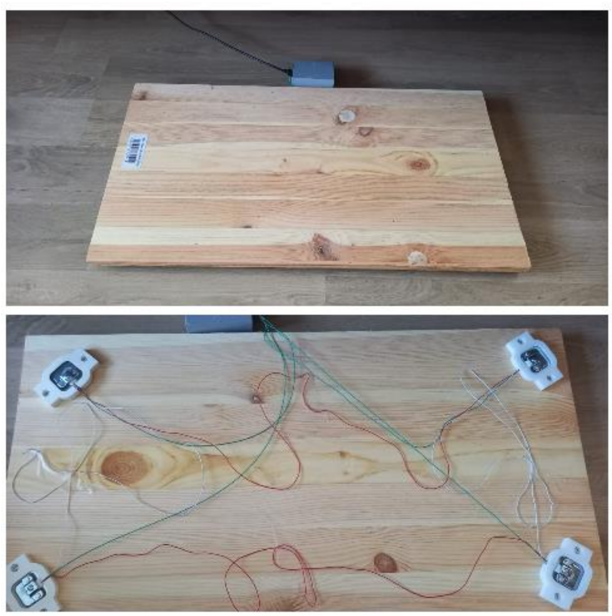

Figure 18. Assembly of the weight sensor into the author's room.

The final mounting of the sensor is installed under the carpet next to the bed to get the data when the elderly wakes up in an automatic way (no need for the elderly to think about going to weight every day). However, it has an inconvenience related to the thickness of the wood and the sensor enclosures which is about 3 cm. This unevenness can cause a fall for the elderly. To solve this problem, it would be appropriate to create a small ramp so that the unevenness is not dangerous or recess the weight sensor into the flooring (more safe but very expensive).

3.5 Smart pillbox

Smart Pillbox has the goal to ensure the owner track every pill to ingest in an easy and simple way. This device can be used in hospitals to prevent errors where many pills have to be given daily to each one of the patients and also in elderly's houses to ensure they do not miss any dose or avoid taking the wrong medicine.

The MedFolio Wireless Pillbox is the device selected for the project, it provides a secure WiFi connection, deep pill compartments hold up to 20-25 aspirin tablets, four optional alerts (beep, flashing LED, email, and text message), real-time medical adherence, and pill identification system displays info up to 16 different medications. The device serves as an electronic medication management device, with the ability to store 7 days of solid medication, divided each one into four daily dosing intervals. One of the alerts the pillbox include is the email alert through the WiFi, this email can be read with the Node-RED and used to integrate this device to the IoT network.

Figure 19. MedFolio Wireless Pillbox (MedFolio Cares, 2021).

Unfortunately, because of the Covid pandemic, the delivery of the device was not on time so it was not possible to document how it will work and how will be integrated into the project.

3.6 Design of the protective case

It was found necessary for fabricating the installation of the different sensors to CAD design and print off 3D enclosures to have the ESP32 and the connections protected to prevent it from being easily manipulated and to keep the wires out of sight of people.

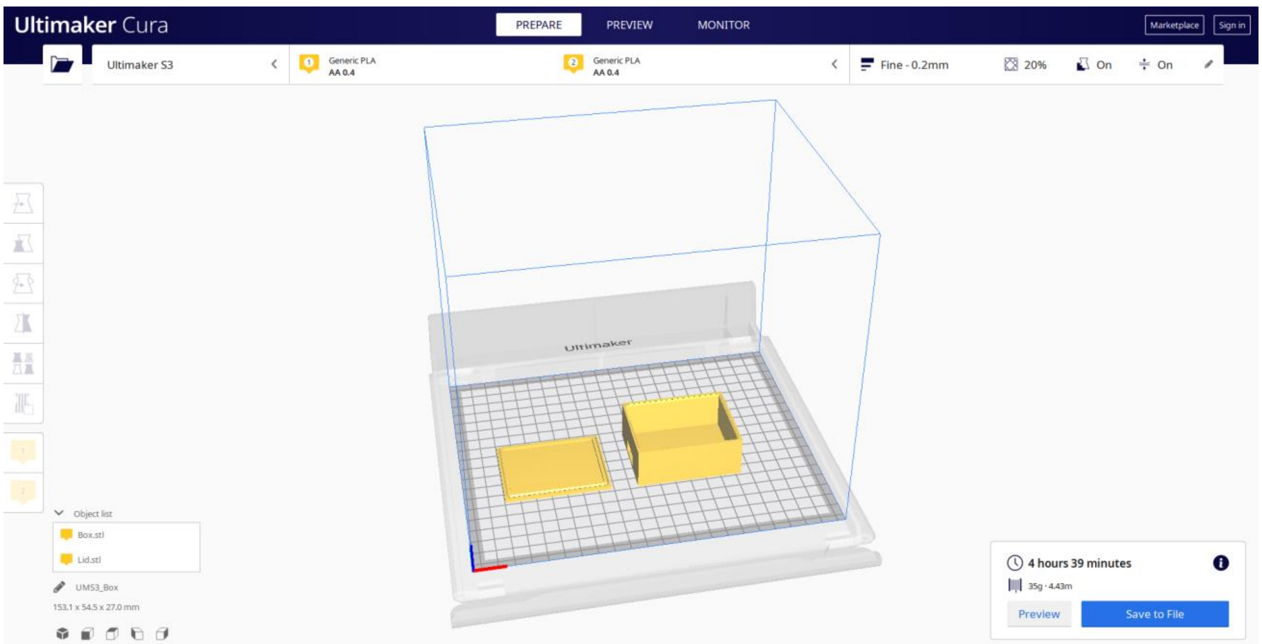

Figure 20. Protective case 3D model in Ultimaker CURA.

Figure 20 shows the prototype of the protective case for each device in Ultimaker CURA. CURA is the world’s most popular 3D printing software and is the one used in Technobothnia. The program converts the CAD design into G-CODE and allows the user to select the Material and the correct properties (layer height, print speed, generate support, printing temperature, etc.).

In the project, four boxes are printed, one for the ESP32 of the door sensors, another one for the weight sensor, and two more for the pressure sensors. The design consists of a box sized 68.0 x 54.0 x 27.0 mm with a hole to get the cables through it with its corresponding lid (as can be seen in Figure 21. The material used is PLA the most common material due to its easy use and low price. The file ".stl" of the 3D model and more photos of the result can be found in Appendix 3.

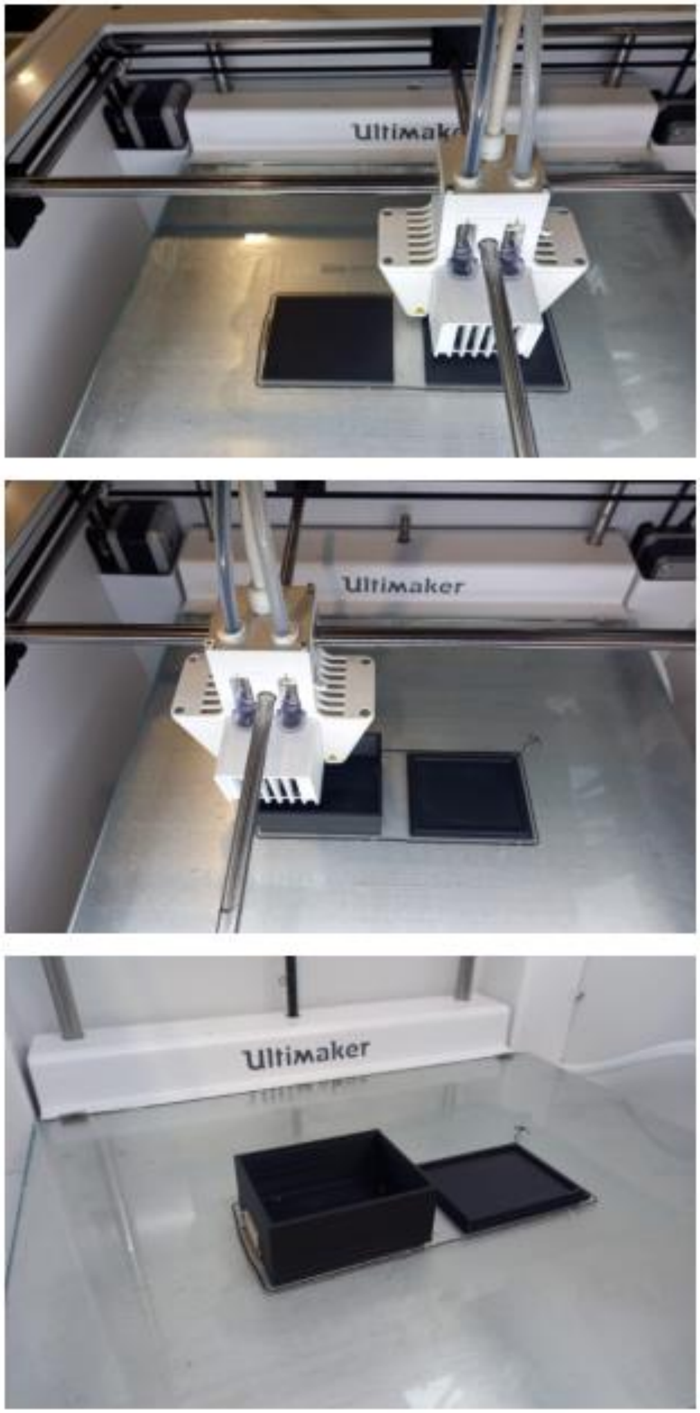

Figure 21. The 3D printing process of the protective case.

4 Test and results

In this chapter, the way how to interconnect the sensors will be explained, such as the transport protocol used, and the Node-RED diagrams developed. Having assembled all the equipment, the IoT network will be tested during one week by taking further measurements and sending alerts when needed.

4.1 MQTT communication

As can be seen in Figure 8**¡Error! No se encuentra el origen de la referencia.**, the communication between the ESP32, the Raspberry Pi, and the medical centre is done via MQTT, this communication allows to collect the data from large networks of small devices into a single location for analysis. This is the reason, why this protocol is ideal for the project's network, the system is collecting data from 4 different sensors and sending it to the Raspberry Pi. The system contains 3 essential components: publisher, broker, and subscriber.

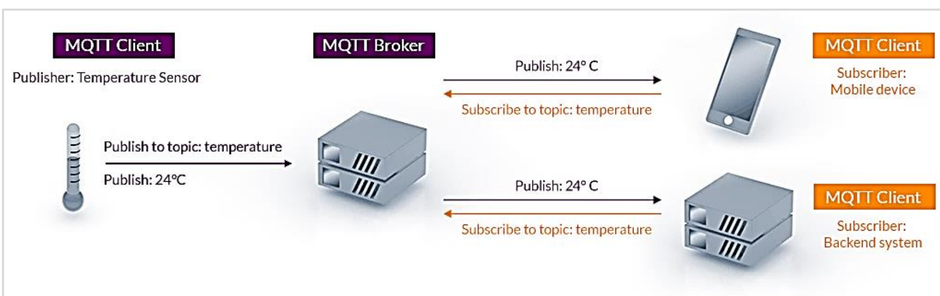

Figure 22. MQTT Publish / Subscriber Architecture.

The MQTT publisher generates and sends the data to the MQTT broker, in the project this function is made by the ESP32 that collects the data of the sensors and sends it to the Raspberry, the MQTT broker that collect all the data. This data is sent to the subscriber, the end user of the project through the Node-RED interface.

To create the MQTT broker it is important to define some settings:

- MQTT Server is the IP address of the Raspberry Pi in the network

- MQTT Topic, each sensor is defined as a different topic to allow the subscriber to distinguish each data.
- MQTT username and password are necessary to create a user and a password in both, publisher and subscribe, to be able to send the data safely.
- MQTT client ID needed to identify the publisher.

To make the MQTT more safety, the default configuration is changed denying access to the anonymous users.

4.2 Data analysis

The data sent to the Raspberry is analysed using Node-RED. The platform will have several different flows, one for each alert needs to be sent to the medical professionals. The alert is sent via Telegram and it is also shown in the interface. This interface will be the Node-RED Dashboard, and can be accessed through the following link when the user is connected to the same WiFi as the IoT network:

http://192.168.1.120:1880/ui

All the JavaScript codes used in the function blocks of Node-RED can be found in the OneDrive folder of Appendix 3.

The first sensor analysed is the door sensor. This sensor sends an alert when:

- The door has been opened for 10 minutes.
- The door is opened during the night. This situation is important to be detected because it can entail that the elderly have left the room caused by some crisis.

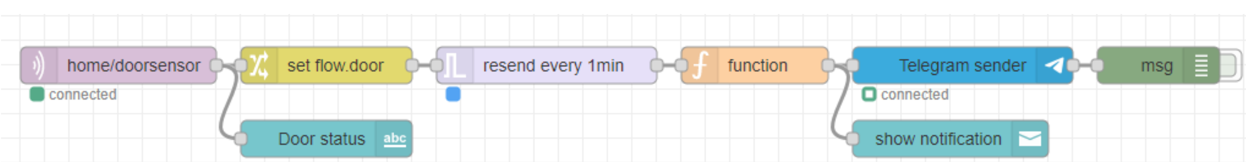

Figure 23. Node-RED door sensor has been open for 10 minutes.

Figure 23 illustrates the Node-RED block diagram that using an MQTT input block, receives the information from the door sensor which detects whether there has been a change of status, i.e., whether someone has opened or closed the door. This input data allows on the one hand to show the status of the door on the Node-RED dashboard and on the other hand to see if the door has been open for 10 minutes. This is done by declaring the variable "door" as a global variable and then sending this variable every 1 minute. Using the function block, then look to see if the variable has the value "o" or "c" (open or closed), if it is open the variable door_open is created and incremented by one, but if it is closed the variable is set to 0. When the variable door_open reaches 10, an alert message via Telegram is sent and a notification on the dashboard is shown.

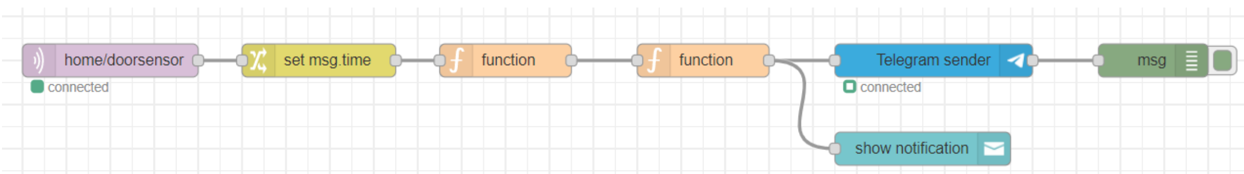

Figure 24. Node-RED door sensor has been open during the night.

The Node-RED used to analyse if the door has been open during the night is shown in Figure 24. The same MQTT input as before is used, moreover, to detect the activity during the night a timestamp variable needs to be set. The first function block is used to get the hours from the timestamp variable, and the second one to send the alert if the payload of the MQTT block is "o" and the time is between 10 pm and 8 am. This alert will be sent through Telegram and will be displayed also as a notification in the dashboard.

The analysis of the pressure sensor has to consider both pressures, the one in the bed and the one in the armchair. These sensors will send an alert if:

- Between 12 pm and 6 am no one is on the bed or the armchair for more than 10 min.

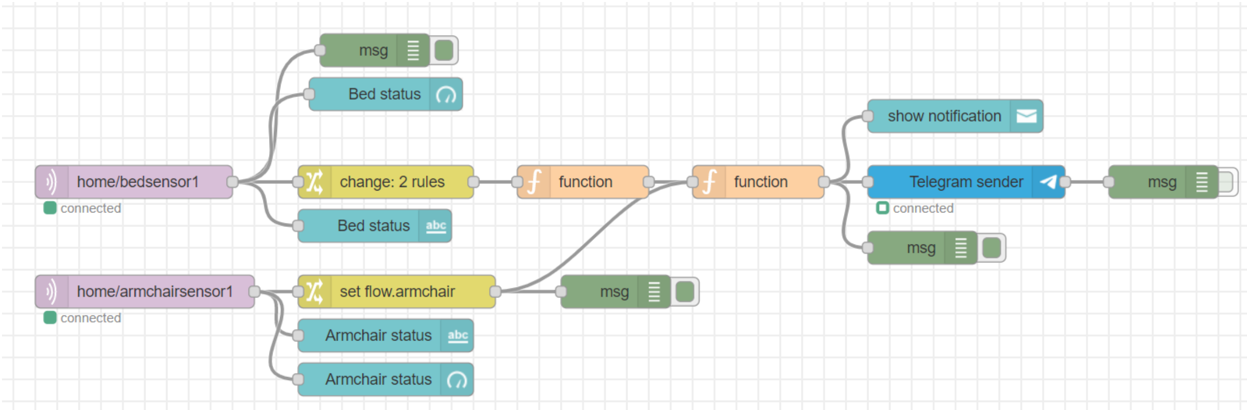

Figure 25. Node-RED pressure sensor for armchair and bed.

As can be seen in Figure 25, the block diagram has 2 inputs, the first is given by the MQTT of the bed sensor and the second by the MQTT of the armchair. In both, the payload is set as a flow variable (bed for the first one and armchair for the second one) and, also the time variable is set using the timestamp.

Inside the function, the variables defined before are read using the command flow.get. After, an "if" structure is created to define the night hours where the alert might be sent. This alert will be sent if the pressure in the bed is less than 2500, the pressure in the armchair is less than 500 and the global variable "counter" reaches the value of 10. Then, it means that for 10 minutes nobody has been in the bed or the armchair and therefore an alert must be sent to the health professionals and reset the counter to 0. Moreover, the two payloads of the MQTT are shown in the dashboard using the edit text node and the gauge node.

The analysis of the weight sensor is the simplest one as can be seen in Figure 26.

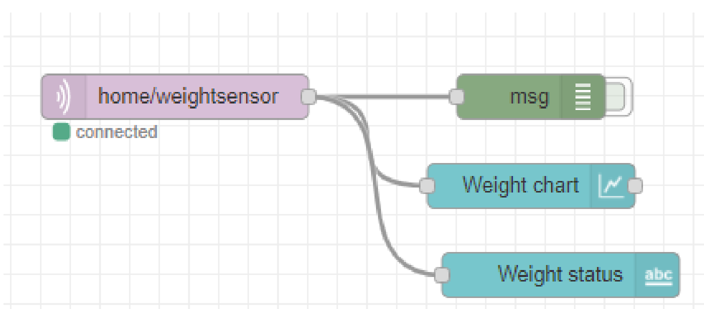

Figure 26. Node-RED weight sensor to create the graphic.

The block diagram is reading the value sent every 1 minute through the MQTT with the topic home/weightsensor and generating the graphic to see the evolution of the weight. The chart node has different properties, for the project the linear type is the optimum one and the x-axis with limits of 1 week has been set. In addition, it also shows the text with the weight value.

4.3 Final interface

The results are shown in the Node-RED dashboard that works as the interface for the nurses to see the actual status of each sensor, as can be seen in Figure 27.

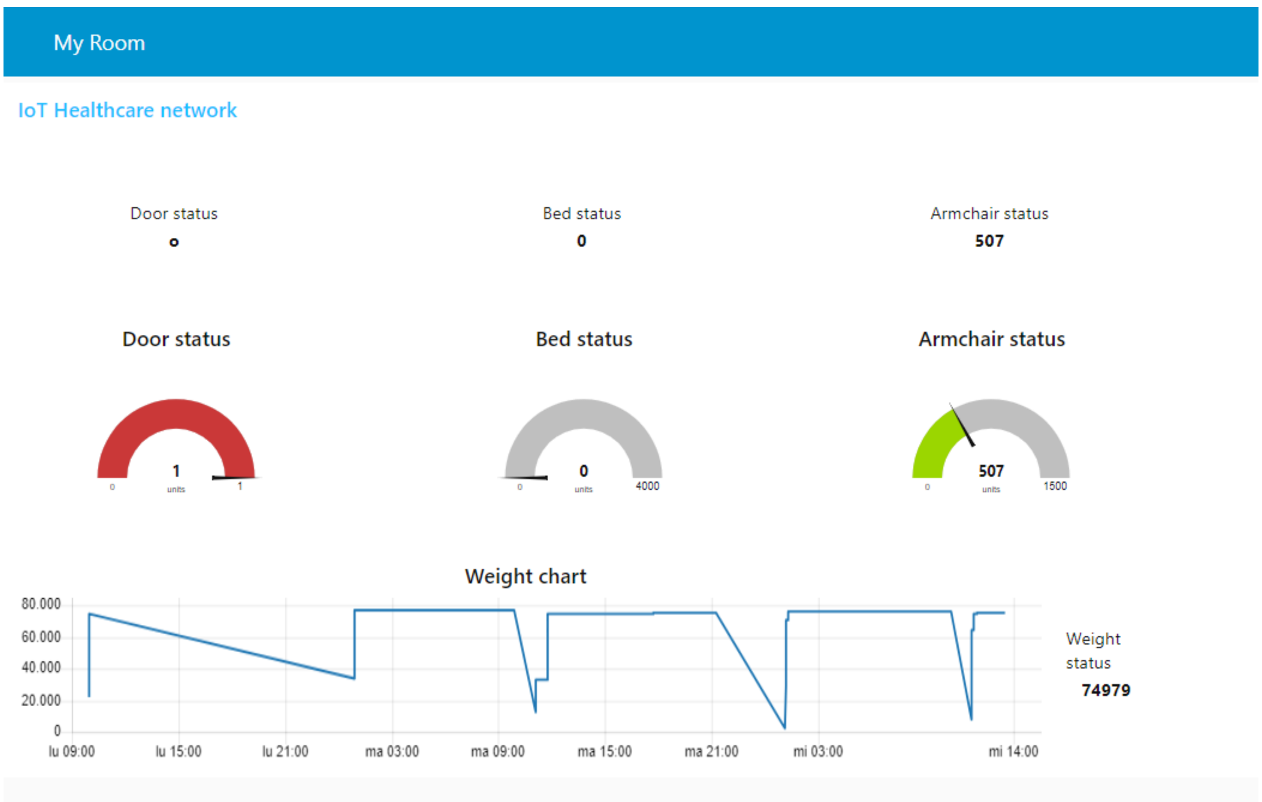

Figure 27. Dashboard of the Node-RED with the actual status of each sensor.

In the previous figure, the status of the bed sensor, the armchair sensor, and the door sensor is illustrated using the text as well as using the gauge to make it more visual. Also, the weight chart is shown to see the variation for one week. In the example, the pressure on the bed was 0 because no one was in the bed, the pressure of the armchair was high so that means that someone was sitting on it, and the door status was open.

Regarding the weight sensor results, it is important to remember that the code is taking the maximum value every 12 hours, this means that the horizontal measurement is the interesting one and is the one that should not change considerably from one time to the other. If there is a pick one day and then it continues to the same weight, is not a problem that needs medical attention because it can be that the elderly was carrying something heavy, however, if it is increasing or decreasing regularly for one week, then it can be considered as an anomaly that needs to be considered as a nutritional problem.

Moreover, the different alerts that are considered as an anomaly are sent through the Telegram app using a bot. The three different alerts that the project analyses are below.

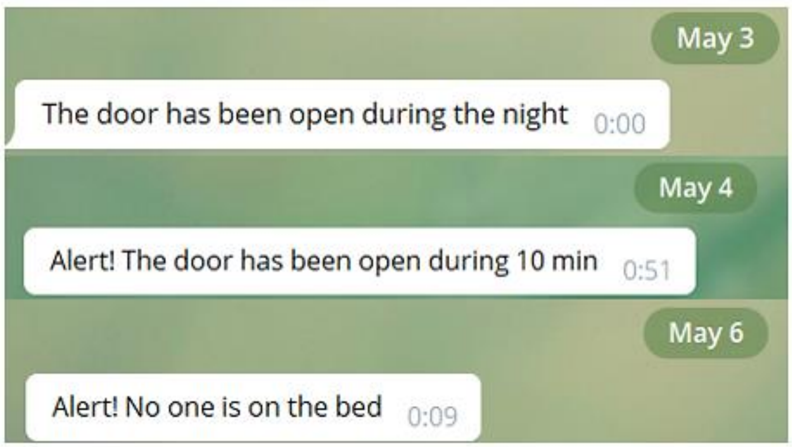

Figure 28. Alerts sent on Telegram's bot.

5 Discussion

This chapter is concerning with the discussion of the initial objectives proposed of the thesis, and the analysis of the results obtained. In addition, the limitations identified and how they have affected the project will be discussed.

The first objective of the thesis was to identify the challenges the elderly have in their daily life. Chapter 2.1 is an overview of why older people have more difficulties in their daily lives, classifying these into emotional, physical, mental and nutritional problems. The results indicate that the main challenges are based on a poor supply of medicines, nutritional issues, and difficulties in carrying out daily activities.

The second objective was to document the status of IoT technology in elderly healthcare, this was handled in Chapter 2.3, first having an overview of what is IoT and the main applications areas, and then having a look at the Healthcare domain and its classification.

The last objective was focused on the development of the IoT network to monitor elderly healthcare in their own home, this was met in the practical framework by implementing the four devices (door sensor, pressure sensor, weight sensor, and smart pillbox) and interconnecting them using the MQTT. In line with the challenges, the IoT network developed can detect if there is an anomaly in each of these areas.

The process followed to create the network was first to research the different devices able in the market, find the best solutions for the problems found, and the selection of the most economical solutions to make the network accessible for everyone. Afterwards, the programming and connection of the different sensors were carried out. Finally, the MQTT was created and added to the C++ programs of each sensor to send the data to the Raspberry. In the Raspberry, the data received was analysed using Node-RED and displayed on the dashboard.

The interface used is simple and understandable, making it easier for medical professionals to analyse the data. In addition, the implementation of alarms via Telegram when there is an anomaly makes it possible to act quickly to detect any problems that may have arisen.

The data obtained, thanks to the accuracy of the sensors, allows problems to be detected quite reliably. However, regarding the weight sensor, there are two impediments. Firstly, as can be seen in Figure 17, the programme is only saving the maximum weight it detects every 12 hours. This can lead to ambiguous results and perhaps it would be a better option to keep the 50 highest values and average them to get a more realistic result. Another impediment of this sensor is when it is installed under the carpet because it has a thickness of about 3 cm, it can cause a fall to the elderly as is mentioned in Chapter 3.4.

The greatest limitation of the project was the difficult access to the simulation room to install all the sensors using the Alere network and the university's MQTT. In addition, the current lack of activity in the room made data collection and future analysis even more difficult. For this reason, the optimal solution found was to install the sensors in the author's room with the need to create an own MQTT to send all the data to the broker. However, after all the data has been collected and the thesis finished, all the sensors will be installed in the simulation room of the university.

Another limitation caused by the pandemic was related to the late delivery of the smart pillbox, which made it not possible to include the results on the Node-RED dashboard. However, the way on how to interconnect it was already planned and organized. The main idea was to use the input email node to detect the emails sent by the pillbox and with them be able to include the device to the interface.

The project is being developed in parallel with the EPS students, who are working on the development of this network with sensors such as motion sensors, humidity sensors, temperature sensors, water flow sensors, etc. This allows the creation of a bigger IoT network, however, due to the different timings, these devices have not been developed yet and therefore they are not included in the final interface.

To sum up, the objectives were achieved successfully, the elaboration of a low-cost IoT network available for all the elderly population with detects some of the challenges they have in their daily life and the notification of anomalies to the medical professionals. Moreover, it is important to integrate more sensors into the simulation room to create a bigger network to be able to detect more anomalies.

6 Conclusion

During the research period, the project has aimed at developing a smart network for assisting the elderly in their homes, to enable them in longer-term independence.

The result of the report suggests the great role that technology can play in improving people's lives, in this case, the health of the elderly. It has seen how IoT can help to prolong the time that older people reside in their homes by reducing the problems they may have and the time it takes to act if there is an accident.

The final systems consist of the realization and inclusion of four smart devices (door sensor, pressure sensor, weight sensor, and smart pillbox) which are costed and integrated into an IoT network using the MQTT protocol. The MQTT protocol offers the benefit of collecting data from small devices (all the ESP32) into a single location for further analysis (the Raspberry Pi) using the existing WiFi network.

These have been tested in the author's apartment to obtain test data and access the determine the potential of the network. The data collected by the Raspberry Pi is analysed using Node-RED, which allows to deal with the results and show them using the dashboard. The dashboard is the interface developed for the medical professionals to show the status of the sensors and sent alerts through Telegram when there is an anomaly.

The limitations posed by Covid 19 prevented the pilot testing of the network in an elderly's home. This would have useful to gain feedback from the end-users, both nurses and the elderly.

Future development of the project would be about making the network more comprehensive with the incorporation of more sensors and the creation of a more dynamic interface that allows digital communication between both end-users.

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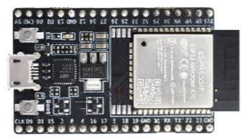
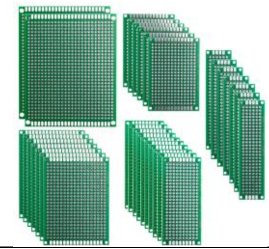
Appendix 1. List of materials used on the project.

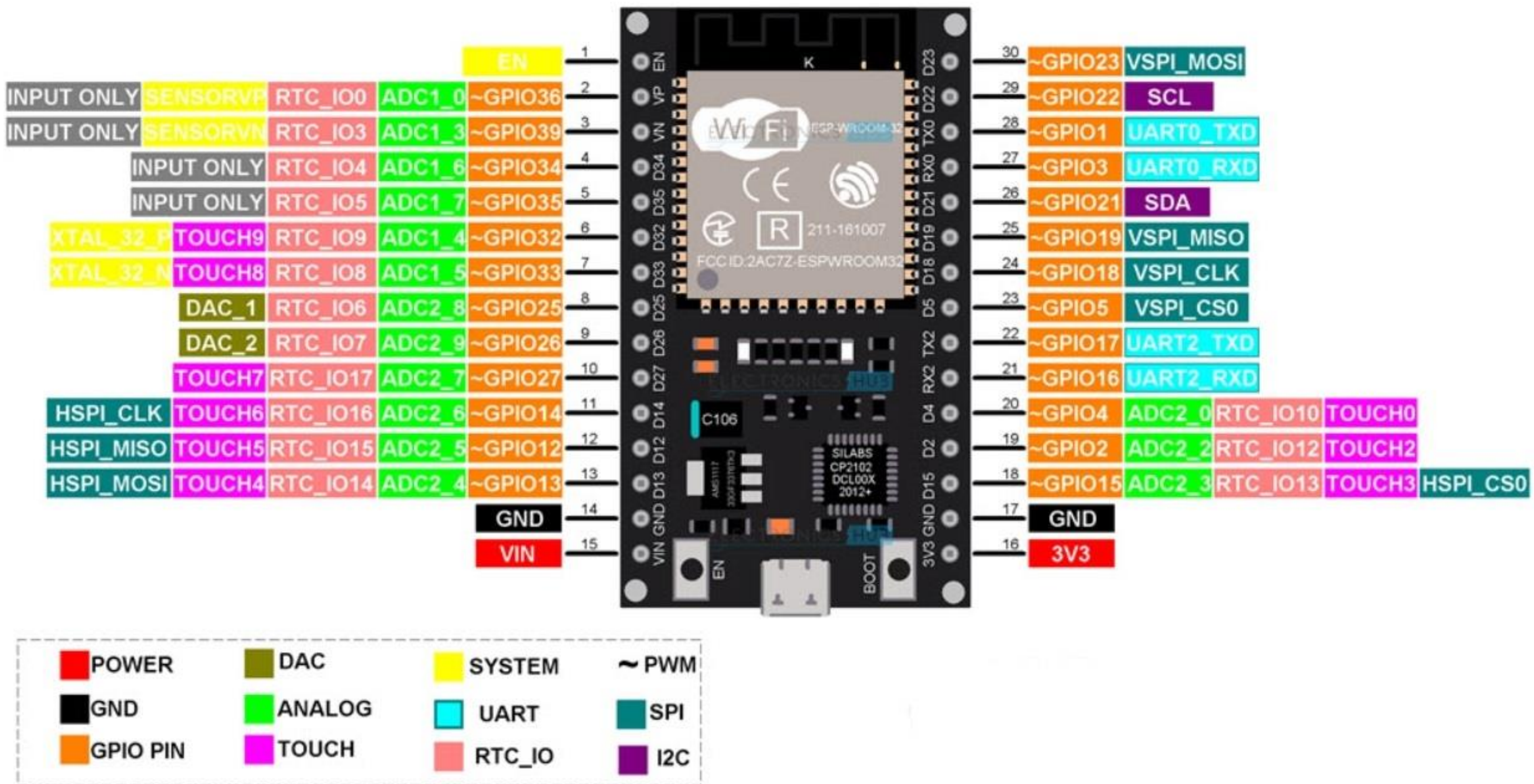
NAME	MANUFACTURER	MODEL	DESCRIPTION	PRICE	UNITS	LINK	PHOTO
ESP32	ESPRESSIF	ESP32-WROOM-32D	Microcontroller with WiFi and Bluetooth, written in C programming and highly integrated.	9,95 €	6	https://www.olimex.com/Products/IoT/ESP32/ESP32-DevKit-LiPo/open-source-hardware	
Raspberry Pi 3	Raspberry Pi community	MODEL B+	Single-board computer with wireless LAN and Bluetooth connectivity. CPU of 64 bits 4 core.	61,9 €	1	https://www.multitronic.fi/en/products/2213751/raspberry-pi-3-model-b---enkortsdator--bluetooth--wi-fi--poe--1gb-ram	
Door sensor	Cashtec Electronic Co.	KMS-30	The magnetic proximity sensor of ABS switched power of 5W, switched current 250mA, switched voltage 110Vac /160 Vdc	3,55 €	1	https://www.starelec.fi/product_info.php?cPath=64_1186&products_id=19475	

NAME	MANUFACTURER	MODEL	DESCRIPTION	PRICE	UNITS	LINK	PHOTO
Large pressure sensor	Cashtec Electronic Co.	KMS-30	Thin Film Resistance 61cm x1.5cm, , Sensor FSR Sensor Force, Sensitive Resistance 10kg, -20 °C to + 60 °C operating temperature	18,39 €	2	https://www.amazon.de/gp/product/B089QKJK8T	
Small pressure sensor	Danyant	SF15-150	Thin Film Resistance 50mm x15mm, , Sensor FSR Sensor Force, Sensitive Resistance 10kg, -20 °C to + 60 °C operating temperature	11,39 €	2	https://www.amazon.de/gp/product/B08B5T9K9S	
Pill Box	ninelife.fi	MedFolio Wireless Pillbox	Built-In WiFi for remote monitoring, deep pill compartments, four optional alerts (beep, flashing LED, email, text message), alert if a dose is missed voltage 110Vac /160 Vdc	363 €	1	https://ninelife.fi/search?type=product&q=medfolio+wireless	

NAME	MANUFACTURER	MODEL	DESCRIPTION	PRICE	UNITS	LINK	PHOTO
Strain gauge weight sensor	Luoyuuk	---	Strain gauge sensor with high accuracy and sensitivity, 50Kg range each one	10,49€	4	https://www.amazon.de/-/en/Fafeicy-Module-Personal-Bridge-Strain/dp/B08DV1YW43/ref=psdc_6589087031_t2_B07TWLP3X8	
Amplifier	Fafeicy	HX711 Module	24-bits A/D converter chip designed for high-precision electronic scales		1		
Resistors	Elegoo	525 kit	Resistor of metal oxide, 0.25 W, from 0 ohms to 50M ohm, 1% tolerance	10.99 €	1	https://ninelife.fi/search?type=product&q=medfolio+wireless	

NAME	MANUFACTURER	MODEL	DESCRIPTION	PRICE	UNITS	LINK	PHOTO
Protoboard	Elegoo	GE-EL-CP-021	32-Piece Double-Sided PCB Board Prototype Breadboard Set for Arts and Crafts, Soldering, Compatible with Arduino Kits	11,69 €	1	https://www.amazon.de/gp/product/B0734XYJPM	
Wires	Donau	D118-HA	Connection Cable of 10m longer, voltage resistance of 60Vcc, 0.14mm^2 with PVC isolation and 1,5A of max capacity.	2,19€	1	https://www.starelec.fi/product_info.php?cPath=79_587_4001&products_id=30636	
Tablet	Power	LENOVO TAB M10 + 10 "64 GT	Android tablet, IPS Full screen HD 10.3", 64 GB storage and 4GB RAM, MicroSD card slot, Andorid 8.1 Oreo, USB C 2,0, Optimal 4G LTE, battery 5000mAh	208 €	1	https://www.power.fi/tietotekniikka/tabletit-ja-tarvikkeet/tablet-tietokoneet/lenovo-tab-m10-10-64-gt-tabletti/p-1054227/	

Appendix 2. ESP32-WROOM-32D Pin Layout



Appendix 3. OneDrive folder of the project

A folder with all the useful material used for the project has been created using OneDrive. The folder includes the 3D printing designs for the boxes of each ESP32 and the weight sensor protections, the device manuals of the ESP32, the Node-RED and the smart pillbox, the flow charts and C++ codes for each sensor, the Node-RED diagrams and codes, and the pictures of the installation of the sensors in the author's room. Moreover, new photos will be added to the folder when the sensors have been installed in the simulation room.

The link to the folder is as follows:

https://yhnovia-my.sharepoint.com