Interreg CENTRAL EUROPE
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# AP-NURSE HOME & CARE MONITORING TOOLS

## D.T2.2.5 - Testing of the Prototype and Finalization of the Tool

Version 1
03 2021

# 1. Introduction

AP-NURSE is a modular and straightforward monitoring tool for patients with Alzheimer's and Parkinson's disease for home and medical application. It encompasses ambient sensors, which can monitor activity patterns, gas, temperature and movement aspects. It aims to simplify home caregivers or nurses' work by monitoring the patient's fundamental interactions with their environment during night or job duties and providing fast alert about possible dangers and support independent living of frail elderly. The deliverable DT2.2.5 is related to the testing of the AP-NURSE Home & Care prototypes including issues of their finalisation. This activity follows deliverables D.T2.2.2 [1] and D.T2.2.3 [2], where the initial versions, application areas, technical schemes and testing procedures were developed and D.T2.2.4 [3], where the first results of laboratory testing were summarized. During the R&D activities and the testing phase, multiple issues were encountered. This report brings the latest details on the development of AP-NURSE devices. Following the development, the new achievements will be included in the updated versions of this report.

# 2. AP-NURSE objectives

## 2.1. Overall description of the system

The main idea of the proposed tools is to bring a cheap and thus widely affordable solution that can monitor the basics interaction of the patient with the environment during night or job duties and provide fast alert about possible dangers. In addition, there are several partial design objectives:

- The tools should follow the needs of real patients (clients of care centres) and caregivers;
- The system should encompass two use cases, to be available for both medical and home application;
- The system should consist of several versions, while keeping the whole system simple and modular
- The tools should encompass ambient contactless sensors to identify changes in the environment;
- The tools should not be in direct contact with patients to prevent detachment or damage;

The development of AP-NURSE devices led to two major versions, AP-NURSE Home and AP-NURSE Care. Both are based on the previously performed market research, presented in D.T2.2.2 [1], and the electronic survey discussed in the next chapter. In the case of AP-NURSE Home, a caregiver wears a simple rubber bracelet (hereinafter wearable) that identifies the incoming signal and warns a caregiver by vibrating. In the case of AP-NURSE Care, a caregiver controls the condition of patients from the nurse/control room on a PC or using a mobile device, visualizing the parameters of AP-NURSE Care utilizing the simple traffic lights logic. The features of AP-NURSE Home & Care are shown in **Table 1**. Both configurations make possible of securely sending anonymized measured data to a dedicated data server for further analysis.

**Table 1: Features of AP-NURSE Home & Care**

| | AP-NURSE Home | AP-NURSE Care |
|---|---|---|
| Home use | ✓ | ✗ |
| Use in care centers | ✗ | ✓ |
| Simple design | ✓ | ✗ |
| Low-cost | ✓ | ⚖ |
| PC based monitoring | ✗ | ✓ |
| Bracelet notifications | ✓ | ✗ |
| IS Data collection | ⚖ | ✓ |

The flowcharts of AP-NURSE Home and Care are shown in **Figure 1** and **Figure 2**. In case of any emergency detected by AP-NURSE Home, a caregiver is notified by the AP-NURSE wearable. It is assumed that patients live with a caregiver therefore to ease the life and not to disturb the caregiver's partner during the night, the bracelet warns a caregiver by vibrating pattern (for communication RF433MHz module with hard encoded addresses is used). In case of the AP-NURSE Care, the caregiving personnel monitoring the conditions of the patients from the nursing room is notified on her/his computer or mobile app. The conditions of the monitored patients are evaluated using a simple traffic light logic, while green light represents normal condition, orange light abnormal condition and red light critical condition.

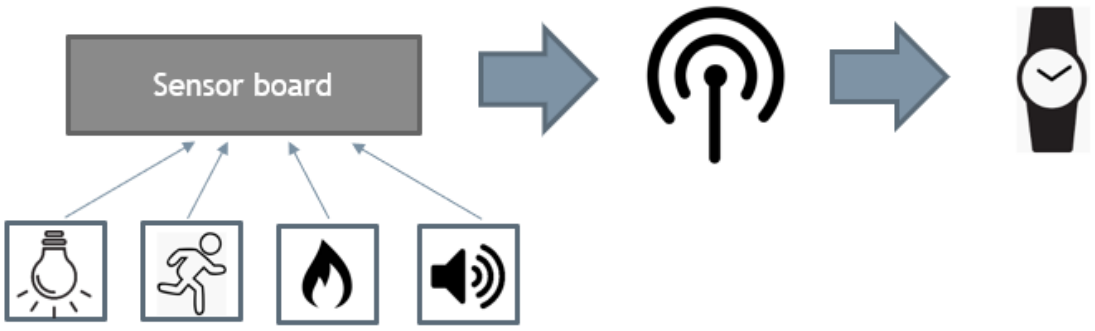



Figure 1: AP-NURSE Home flowchart

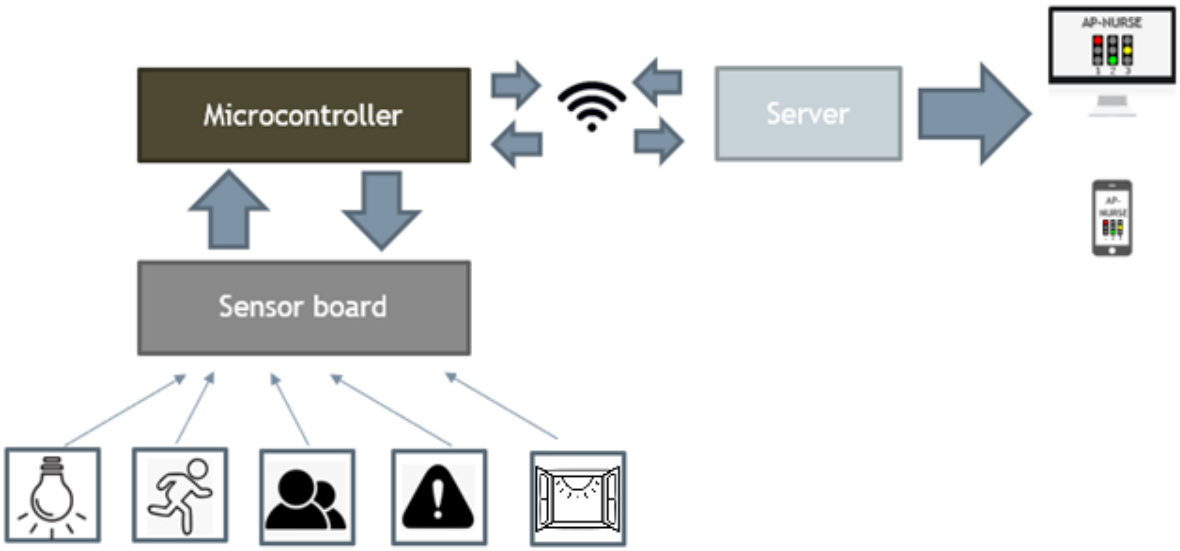



Figure 2: AP-NURSE Care flowchart

## 2.2. AP-NURSE use cases

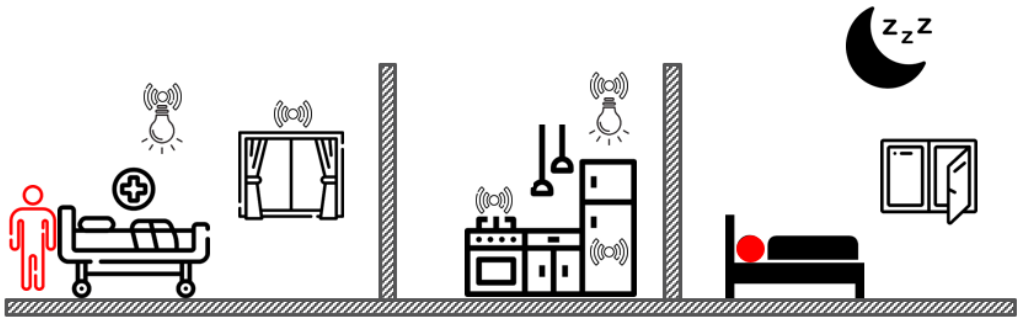
For both AP-NURSE Home and Care version unique use-cases were defined, the “Home environment” and the “Care center”. These use-cases are defined in the following section.

### 2.2.1. Use-case: Home environment

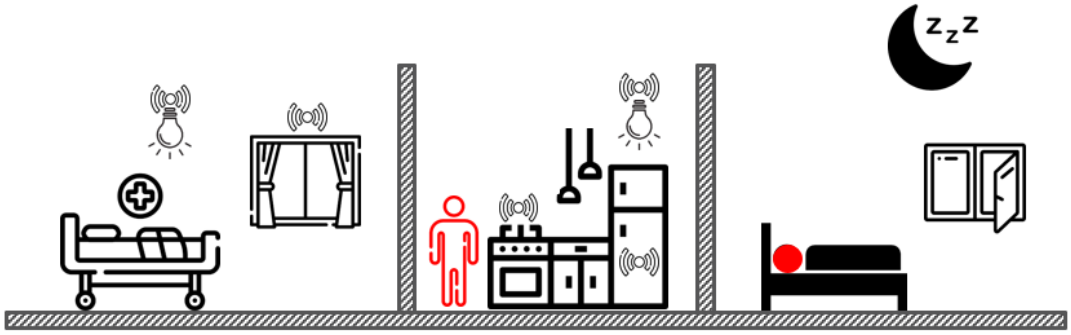
A simple use-case of the AP-NURSE Home solution can be seen in **Figure 3** (numbers represents the steps prior to the actuation of AP-NURSE). This use-case represents a routine use of AP-NURSE in the home environment where the patient suffering from Alzheimer’s or Parkinson’s disease lives with his/her caregiver, who is usually a member of his family.

1. The patient, who had been sleeping, woke up and stepped out from the bed.
2. As part of his/her routine the patients moved towards to kitchen or any room where AP-NURSE is installed.
3. As the patient switched on the light, opened the fridge or turned on the gas stove, AP-NURSE notified the change in the environmental parameters and warned the caregiver who had been sleeping in the next room.
4. The caregiver, who woke up due to the vibrating bracelet, turned off all electronic/gas appliances and put the patient back to bed.

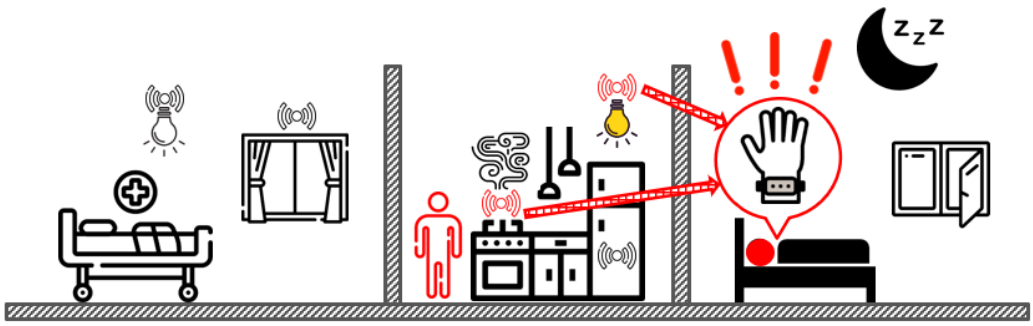
(1)




(2)




(3)



(4)

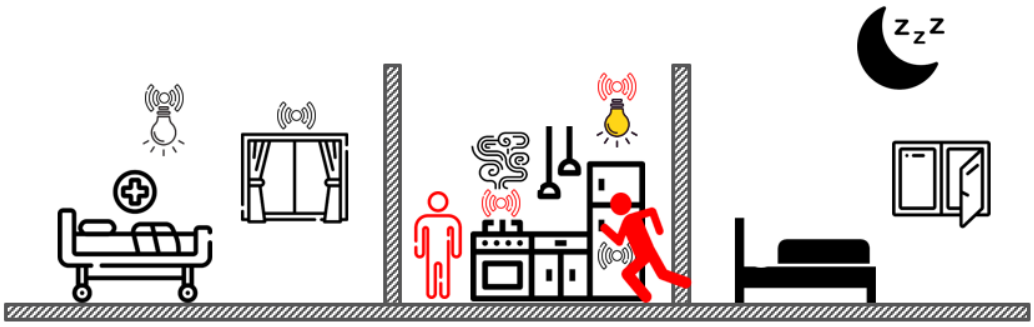


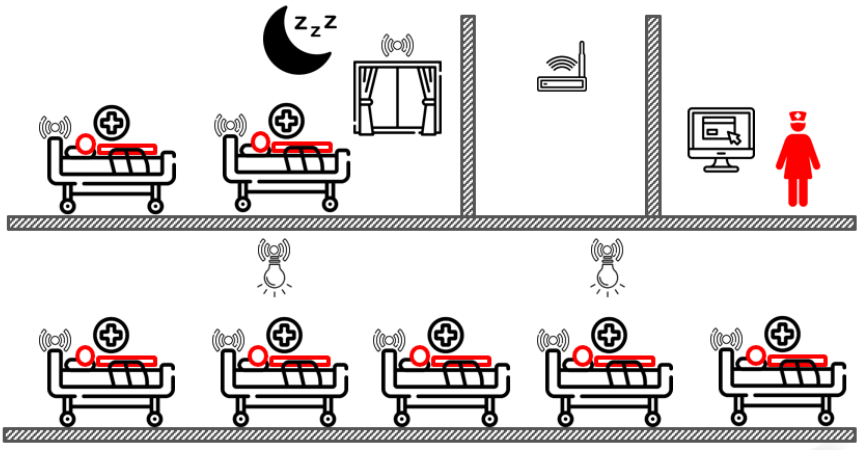
**Figure 3: Home environment use-case** [4]

### 2.2.2. Use-case: Care center

A simple use-case of the AP-NURSE Care solution can be seen in **Figure 4.** (numbers represent the steps prior to the actuation of AP-NURSE). This use-case represents the use of AP-NURSE in the care centre where multiple patients from Alzheimer's or Parkinson's disease are accommodated in rooms while their conditions are monitored by the professional personnel from the nursing room.

1. One of the patients, who had been sleeping, woke up and stepped out from the bed.
2. As the patient started to move in the room equipped by multiple AP-NURSE sensors, the PC or the APP installed on the mobile of the caregiving personnel provided the first notification, classified as warning.
3. By switching the lights on the patient actuated multiple sensors and the PC or mobile provided the next notification and required the personnel to intervene.
4. The caregiver, notified by PC or his/her mobile, put the patient back to bed, made sure the remaining patients were safe and reset the PC/APP notifications.

(1)



(2)

(3)

(4)

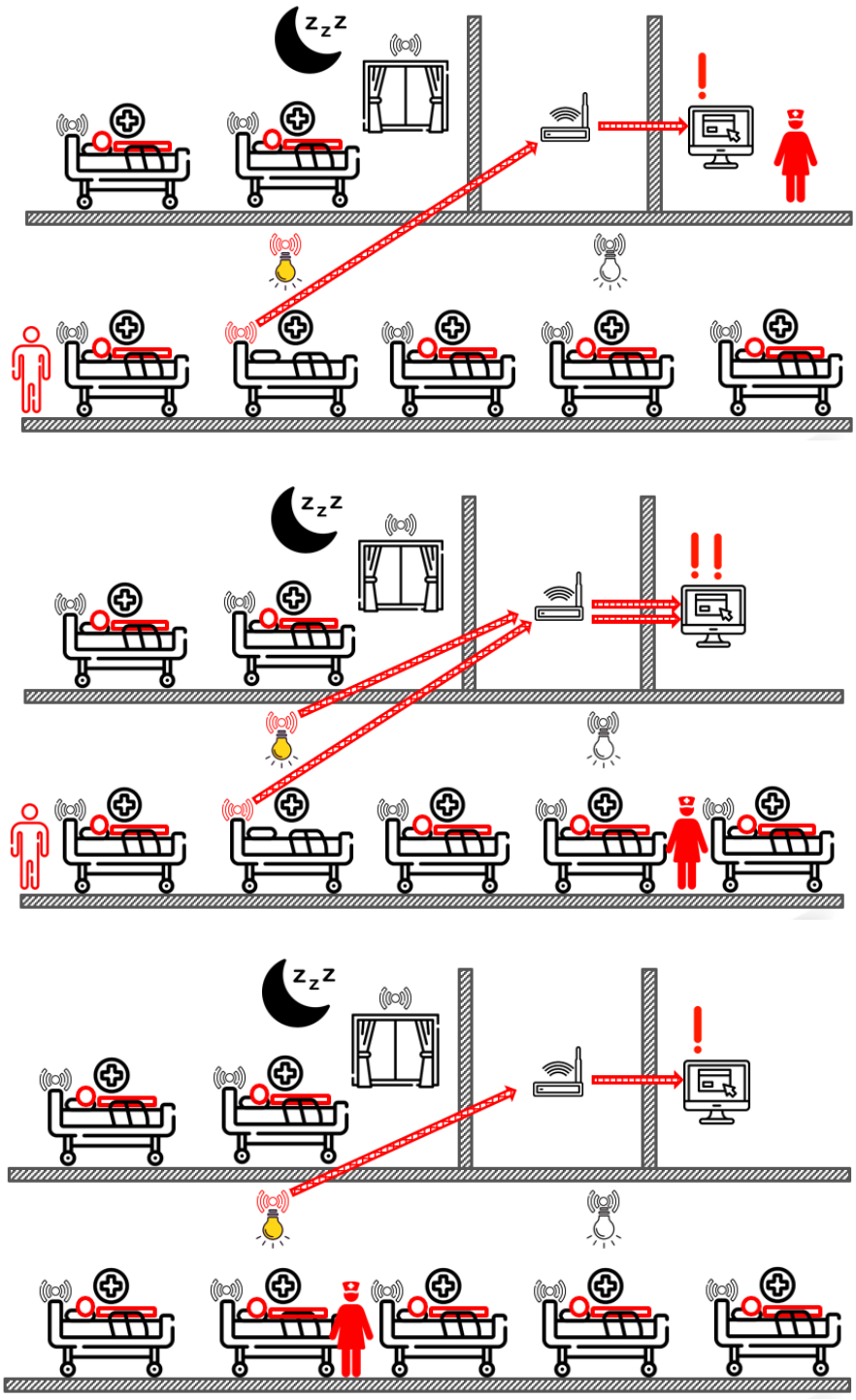


Figure 4: Care center use-case [4]

## 2.3. Requirement of the system design

Both AP-NURSE Home and Care consist of a set of sensors carefully selected to identify the most important events that could occur, when the patients' behaviour differs from normal conditions, i.e. the patients stands up, turns on the light, falls down, opens the window etc. The selection of appropriate sensors is based on the experience of project partners operating care canters and social homes in Bratislava, Warsaw and Olomouc. In order to collect information from the potential user of AP-NURSE and project partners involved in the testing of devices an electronic questionnaire using the LimeSurvey online platform was created. The questioner consisted of 65 questions focusing on the type of the diseases of treated patients/clients, the experience of the caregivers with IoT (internet of things) solutions, their needs and requirements specific to their treated patients/clients. The questionnaire was accessible through a unique URL address and TOKEN, which served to identify the partner filling the survey. The summary of involved institutions is shown in **Figure 5**. More details and graphical outputs of the survey can be found in the former D.T2.2.3 [2] deliverable.

| Answer | Count | Percentage |
|---|---|---|
| Petržalka Municipal District of Bratislava - Capital city of Slovakia (A1) | 2 | 33.33% |
| Brno University of Technology (A2) | 0 | 0.00% |
| The University Hospital Olomouc (A3) | 2 | 33.33% |
| Slovak University of Technology in Bratislava (A4) | 0 | 0.00% |
| LEPIDA SCPA (A5) | 0 | 0.00% |
| Local Health Authorithy of Bologna (A6) | 0 | 0.00% |
| Institute for elderly care and shelter (A7) | 0 | 0.00% |
| Samaritan Burgenland Department of Home Care (A8) | 0 | 0.00% |
| Miasto Sto?eczne Warszawa (A9) | 0 | 0.00% |
| National Institute of Public Health (10) | 0 | 0.00% |
| St. Cyril and Method Hospital, Bratislava (B1) | 0 | 0.00% |
| Bratislava self-governing region (B2) | 0 | 0.00% |
| Central European Insitute of Technology (B3) | 0 | 0.00% |
| St. Anne Univesrity Hospital (B4) | 0 | 0.00% |
| Emilia Romagna Regional Agency for Health and Social Care (B5) | 0 | 0.00% |
| Association of associations for the development volunteering (B6) | 0 | 0.00% |
| Health care center Maribor (B7) | 0 | 0.00% |
| Municipality of Maribor (B8) | 0 | 0.00% |
| Municipality of Olomouc City (B9) | 2 | 33.33% |
| Olomouc Region (B10) | 0 | 0.00% |
| ALZHEIMER UNITED ITALY ONLUS (B11) | 0 | 0.00% |
| European Local Institution and Social Action in Europe (B12) | 0 | 0.00% |
| Other | 0 | 0.00% |
| No answer | 0 | 0.00% |

**Figure 5: Summary of involved institutions in the survey**

The survey has been completed by 6 users representing 3 institutions, the Petržalka Municipal District of Bratislava, The University Hospital Olomouc and the Municipality of Olomouc City. Among them, 3 institutions are involved in the care of patients suffering from frail elderly and 3 have experience with all listed chronical diseases (Alzheimer disease, Parkinson's disease and Frailty elderly). Regarding the behaviour of treated patients, the partners responded that their patients live in their own reality, lost, without or in limited contact with their environment. They also suffer from confusion, loss of self-care, need of an accompanying person and separation.

Two out of six respondent claimed that they already have experience with IoT solutions for monitoring the conditions of their patients. Five out of six respondent claimed that they would use IoT solutions for monitoring the conditions of their patients / clients in the future. The results showed that the users of the IoT solution will prefer the combination of motion (5 counts), sound (4), gas (4), temperature (4), pressure (3) light (2), humidity (2) and the opening/closing event (2) sensors.

Five out of six respondent found the IoT solution important to provide sound notifications both to the patient and the care giver. Only 33 % of respondents think that it is appropriate to notify only the care giver. In case of system that provides notification on a smartphone or PC/laptop, normal behaviour of the patient should be signalized by green light on the screen. Abnormal condition of the patient should be signalized by

yellow light on the screen, with modest alarm beep and by message on mobile phone. In some cases, it would be also preferable to provide a map to the location where the behaviour was observed. The critical condition should be signalized by red light, strong alarm and by message to pager/smart phone. It would be also important to provide information on the patient, i.e. name, room number, map.

When bracelet is used for notifications, the respondent claimed the normal behaviour should either be not signalized or signalized by green light on the bracelet. Abnormal condition should be indicated by yellow light and mild vibration of the bracelet. Critical condition should be signalized by strong vibration, red light and loud sound on the bracelet. The users indicated, that low battery level of the bracelet should be also indicated by flashing light or vibration. 33 % of respondent claim the bracelet to be connectable to a smartphone.

## 2.4. AP-NURSE technologies

The construction of the AP-NURSE units is divided into two branches based on the proposed systems (Home and Care). The AP-NURSE Home is an in-house solution, developed from the scratch, utilizing the ESP8266 microcontroller. In the case of AP-NURSE Care, the porotypes are based on two available modular systems, the M5Stack and the Waspmote platforms. Both solutions achieve high modularity and provide high level of inter-connectivity. In the following sub-sections, brief information on the selected hardware solution can be found. For more details see the previous D.T2.2.2 [1], D.T2.2.3 [2] and D.T2.2.4 [3] deliverables.

### 2.4.1. Inhouse ESP8266 solution

This inhouse solution consists of all phases of development, starting from the PCB design, production, and folding. As its core unit it uses the ESP8266 microcontroller. The ESP8266 is a low-cost Wi-Fi microchip, with a full TCP/IP stack and microcontroller capability, produced by Espressif Systems in Shanghai, China. The chip was introduced in the Western makers in August 2014 with the ESP-01 module, made by a third-party manufacturer Ai-Thinker. This small module allows microcontrollers to connect to a Wi-Fi network and make simple TCP/IP connections. The very low price and the fact that there were very few external components on the module, which suggested that it could eventually be very inexpensive in volume, attracted many hackers to explore the module, the chip, and the software on it, as well as to translate the Chinese documentation. The ESP8285 is an ESP8266 with 1 MiB of built-in flash, allowing the building of single-chip devices capable of connecting to Wi-Fi. The ESP3288 microcontroller is shown in **Figure 6.** The real PCB designs and configurations can be found in the next sections [5].

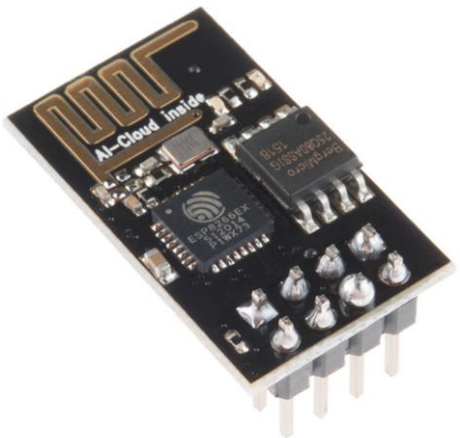



**Figure 6: ESP3288 core units** [5]

### 2.4.2. M5Stack

The first hardware architecture selected for the AP-NURSE Care platform is the modular M5Stack solution. M5Stack is modular stackable product development toolkits based on ESP32 (The world's most popular Wi-Fi SoC, upgrade of ESP8266). The M5 ecosystem consists of the main unit (core unit), stackable modules and bases, grove compatible sensors "units" and different applications for industry IoT. M5Stack is committed to providing easy-to-develop and cost-effective IoT devices.

The main hardware units (**Figure 7**) of the M5Stack solution implemented in the AP-NURSE Care design are the M5StickC, 18650 HAT, Power C HAT and a couple of stackable sensors.

a; M5StickC Plus b; 18650 HAT c; Power C HAT

**Figure 7: M5Stack hardware units** [6]

**M5StickC Plus** is a mini M5Stack core unit, powered by ESP32 microcontroller, which is a single 2.4 GHz Wi-Fi and Bluetooth combo chip and integrates a 4-MB SPI flash. It is a portable, easy-to-use, open-source, IoT development board. M5stickC is one of the core devices in the M5Stack product series. Hat ENV unit It is the core unit used to detect the temperature, humidity, air pressure and magnetic field.

**18650 C HAT** is a rechargeable battery base, designed for M5stickc with built-in 18650 large capacity rechargeable lithium battery. It can provide long-term endurance for the equipment. The base is designed with the plug-in structure of the HAT series, which can be used to maintain reliable connection with the M5StickC. The bottom is equipped with a USB type C charging interface, which is convenient and can quickly charge the battery. The USB port of the battery base is only used as a charging interface, and does not have UART function. There are many types of mounting holes on the back of the base, which can be easily installed by the user into all types of planes.

**PowerC** HAT is a charging module specially designed for m5stickc, with built-in ip3005 high-precision lithium battery protection IC and ip5209 power management IC. It uses the I2C communication protocol to carry out data transmission with m5stickc of the host computer and can check the voltage, current, and other information [6].

In order to meet the requirements of using AP-NURSE Care in care centers, the core units will be equipped with several simple but robust M5stack sensors. The number of sensors per one module is limited to 5 pieces. The configuration of sensors depend on the specific application, thus each AP-NURSE version is equipped with a unique configuration of sensors. More details on the available sensors can be found in D.T2.2.2 [1] and their real configurations are shown in the next sections.

### 2.4.3. Waspmote

The second hardware architecture selected for the AP-NURSE Care platform is the Waspmote, which has been specially designed for work with extremely low power consumption. Digital switches allow to turn on and off any of the sensor interfaces as well as the radio modules. Waspmote supports more than 120 sensors and 15 wireles interfaces which gives to Waspmote flexibility to be applicable in any situation and environment. [7]. The main hardware units (**Figure 8**) of the Waspmote solution implemented in the AP-NURSE Care designs are the Waspmote motherboard, the expansion modules, the wireless module and the sensors.

a; Motherboard b; Expansion Modules c; Wireless Module

**Figure 8: Waspmote hardware units** [8]

**The Waspmote motherboard** design is prepared for the integration of both inputs (sensors) and outputs (actuators), which allow growing the wide range of existing base. The new sensors can be connected to the Waspmote's 2x12 and 1x12 pin connectors.

**The Expansion** modules serve for the integration of sets of sensors based on application requirements. This integration requires some type of electronic adaptation or signal processing prior to reading by the microcontroller. Combination of the variety of sensors and expansion modules, a wide range of applications can be achieved.

**The Wireless module** is based on the WiFi PRO module which supports the SSL3/TLS1 protocol for secure sockets. On the WLAN interface, it supports WEP, WPA and WPA2 WiFi encryption. The WiFi PRO module may connect to any standard router which is configured as Access Point (AP) and then send data to other devices in the same network such as laptops and smartphones. Besides, they can send data directly to a web server located on the Internet. [8]

The core units of the Waspmpote AP-NURSE Care solution are equipped with several sensors. The configuration of sensors depend on the specific application, thus each AP-NURSE version is equipped with a unique configuration of sensors. More details on the available sensors can be found in D.T2.2.2 [1] and their real configurations are shown in the next sections.

## 2.5. AP-NURSE versions

The electronic survey presented in chapter 2.3 identified several issues that directly influence the development of AP-NURSE devices. It was found out, that in the care centers patients with various diseases and different stages of diseases are treated. Some of them are immobile bedridden ones, others are allowed to walk around the center and enter kitchen areas, toilets, common rooms and even outdoor premises. Another important fact is the difference in the daily and night routines of the patients and personnel. During the day, mobile patients are allowed to move, however night wonderings are strictly prohibited for all

patients. The electronic survey also identified, that there is a need for motion, sound, gas, temperature, pressure, light, humidity and opening/crossing event sensosr, while their combination depends on the types of patients and their regimes. It is therefore obvious that a single monitoring device could not sufficiently cover all application areas and thus several version of AP-NURSE Home and Care should be introduced. During the development process 8 versions of AP-NURSE were developed, some available for all hardware platforms, other only for a specific platform. Several versions also showed to be useless, therefore omitted from further development. The final list of AP-NURSE versions are shown in **Table 2,** including their ID, name and information regarding the hardware platform, for which it applies.

**Table 2: AP-NURSE versions**

| AP-NURSE version name | | AP-NURSE version ID | Applies for devices |
|---|---|---|---|
| **AP1** | Monitoring device under the bed | **AP1-H** | Home |
| | | **AP1-M** | Care - M5Stack |
| | | **AP1-W** | Care - Waspmote |
| **AP2** | Monitoring device placed at the doors to toilets in patient´s/client´s room | **AP2-H** | Home |
| | | **AP2-M** | **Care - M5Stack** |
| **AP4** | Monitoring device in common rooms, stairs, forbidden zones for patient´s/client´s | **AP4-H** | Home |
| | | **AP4-M** | Care - M5Stack |
| **AP6** | Monitoring device in kitchen | **AP6-H** | Home |
| | | **AP6-M** | Care - M5Stack |
| **AP7** | Monitoring device in patient´s/client´s room | **AP7-H** | Home |
| **AP8** | Fall down detection device | **AP8-W** | Care - Waspmote |

The brief description of AP-NURSE versions is the following:

- AP1 version is meant to be placed under the bed of mobile patiens or clients of care centers, to monitor basic movement around the room, noise and patient's movement in the bed.
- AP2 is designated to monitor the doors to the bathroom of mobile patiens or clients of care centers. Opening the door will trigger the sensor and based on the time delay and optional noise sensor will trigger the alert.
- AP4 should be placed in common places, such as stairways or hallways, to monitor mostly movement during the night, or for monitoriting of forbidden areas.
- AP6 is designed to be used in a kitchen like environment, aimed mostly on gases and smoke.
- AP7 is designed to be placed in the room of mobile patients, similar to AP1, however in various locations, not undter the bed.
- AP8 is designed to identify falling down of a patient/client out of the wheelchair.

As can be seen, there are six main AP-NURSE versions, which are further divided based on the used hardware platform leading to 11 total AP-NURSE prototypes. These prototypes difer in the possible event in near their proximity and patient's mobility, therefore they encompass different sets of sensors. The simple lists of sensors utilized for each version are shown **Table 3 - Table 5.** Detailed overview of the AP-NURSE versions and configuration of sensors can be found in D.T2.2.4 [3].

**Table 3: Simple list of sensors of the AP-NURSE Home versions**

| AP-NURSE version | Sensor configuration | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mov. | Bar. | Force | Gas | Temp. | Light | Fall |
| AP1-H | ■ | | ■ | ■ | ■ | ■ | |
| AP2-H | ■ | | | | | | |
| AP4-H | ■ | | | | | | |
| AP6-H | ■ | | | ■ | | ■ | |
| AP7-H | ■ | | | ■ | ■ | ■ | |

**Table 4: Simple list of sensors of the AP-NURSE Care M5Stack versions**

| AP-NURSE version | Sensor configuration | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mov. | Bar. | Force | Gas | Temp. | Light | Fall |
| AP1-M | ■ | | | ■ | ■ | | |
| AP2-M | | ■ | | | | | |
| AP4-M | ■ | | | | | | |
| AP6-M | ■ | | | ■ | ■ | ■ | |

**Table 5: Simple list of sensors of the AP-NURSE Care Waspmote versions**

| AP-NURSE version | Sensor configuration | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mov. | Bar. | Force | Gas | Temp. | Light | Fall |
| AP1-W | ■ | | ■ | ■ | ■ | ■ | |
| AP8-W | | | ■ | | | | ■ |

*Explanatory notes:*

- ***Mov.*** Movement - PIR sensor
- ***Bar.*** Barrier crossing - ToF sensor
- ***Force*** Pressure stripe - FSR sensor
- ***Gas*** Gas detection sensors - MQ-135, MQ-5 or BME680 sensor
- ***Temp.*** Temperature - BME280 or BME680 sensor
- ***Light*** Light sensor
- ***Fall.*** Falling down - accelerometer sensor

# 3. AP-NURSE design

## 3.1. AP-NURSE Home

### 3.1.1. Hardware

AP-NURSE Home is based on the NodeMcu ESP8266 microcontroller that monitors the environment via multiple sensors attached. The hardware components and connectivity schemes of the sensors to ESP microcontroller and the technical descriptions of components can be found in D.T2.2.2 [1] and D.T2.2.3 [2]. After the testing all of the chosen components, the circuit schematics were designed for both the AP-NURSE Home ***base*** and ***wearables***. These circuits have gone through several iterations. The final version of the AP-NURSE Home base and wearables are shown in **Figure 9** and **Figure 10.**

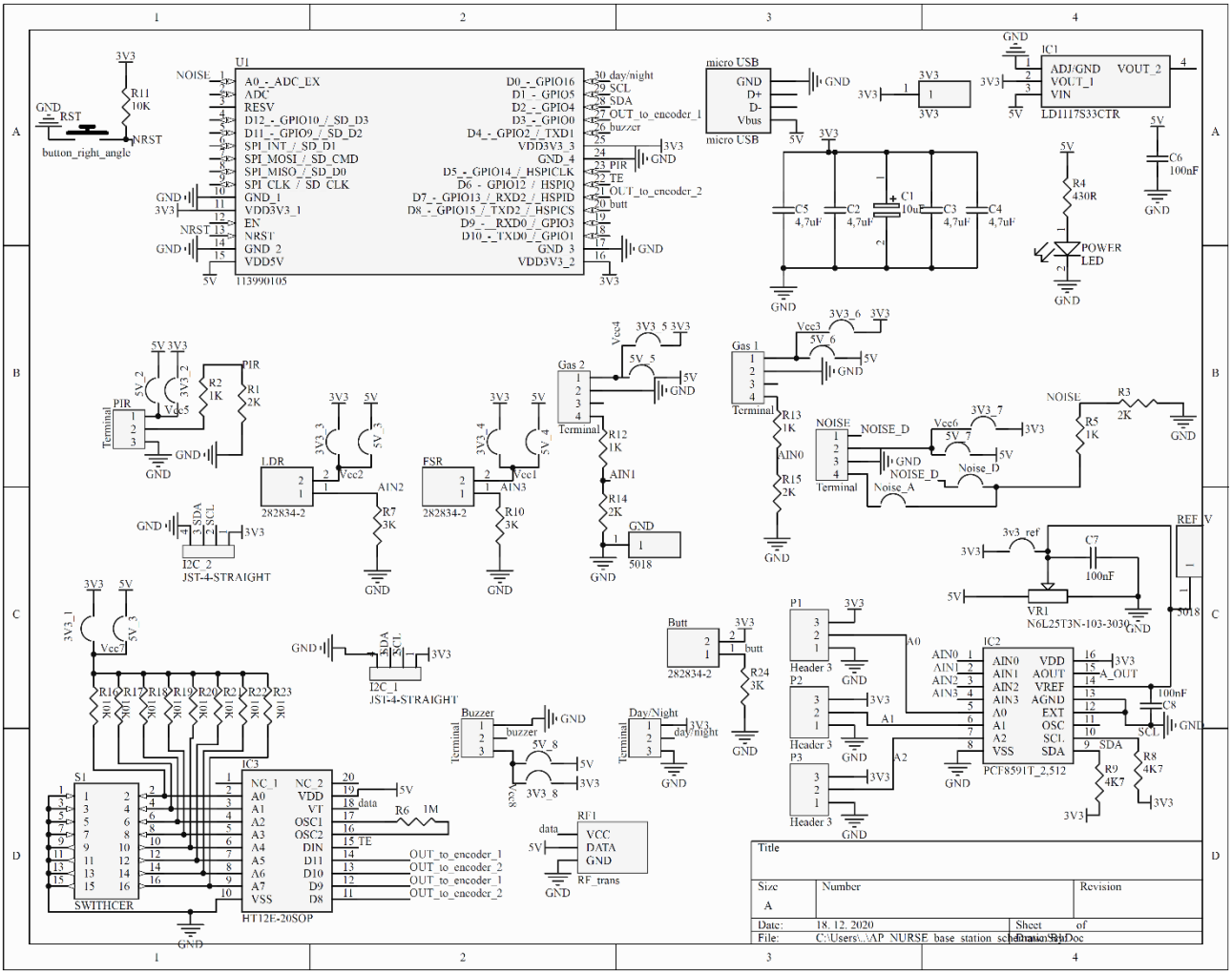



**Figure 9: Final AP-NURSE Home base schematics**

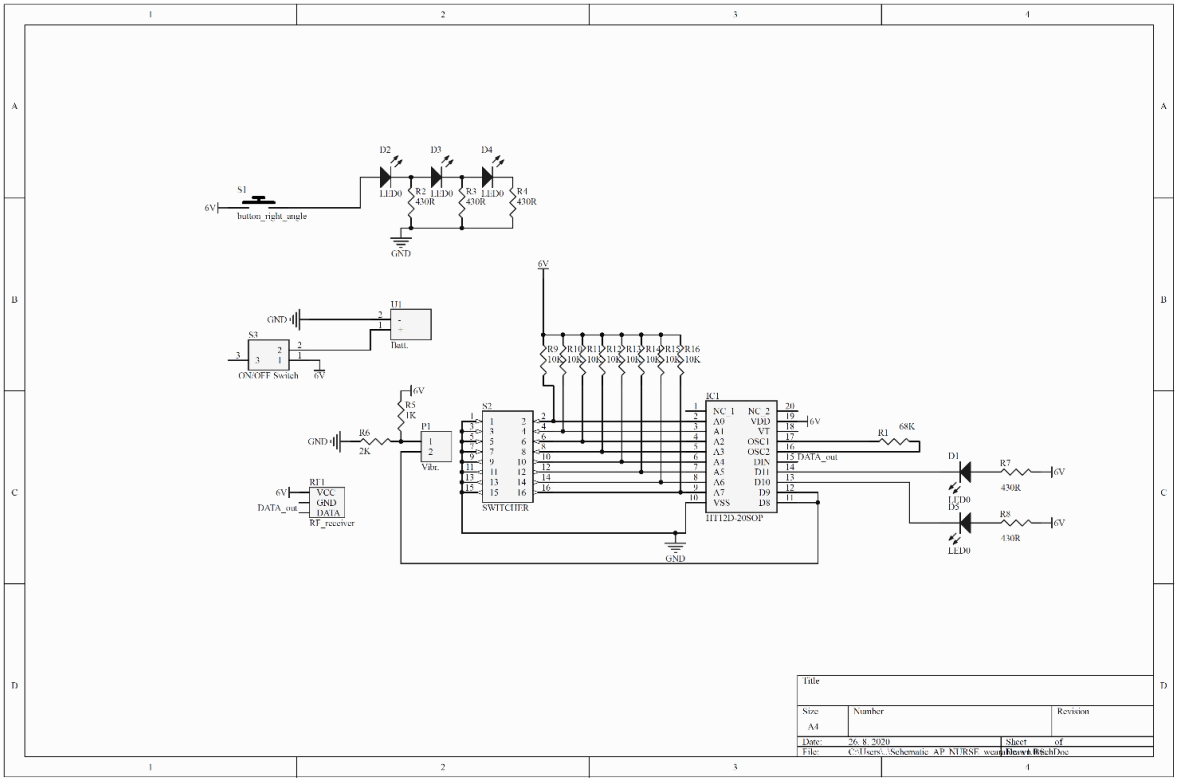



**Figure 10: Final AP-NURSE Home wearables schematics**

Based on these schemes, prototype PCB circuit boards were designed for manufacturing. The sensors are connected to the appropriate headers directly or by extending cables to ensure effective and portable casing design of whole device. In this design two buttons are embedded in the casing, one restart button and one programmable event button on the top lid of the casing. Day/night switch is also embedded in the casing. Inside of the casing there is an address switcher, which is used to change the signal addresses of the encoder for the parallel communication of multiple nodes. The power supply of the AP-NURSE Home base may be direct from the wall outlet or if necessary, from power bank.

#### 3.1.1.1. AP-NURSE Home versions

The configuration of sensors for each AP-NURSE Home device is shown in **Table 3.** Based on the electronic survey and the outcomes of tests performed in previous periods of the project 5 AP-NURSE Home versions were created. The schematic hardware configurations with the assembled devices are shown in next sub-sections. Each configuration consist of the PCB board with the ESP8266 microcontroller and several connected peripheral componets. Each version of AP-NURSE Home could be equipeed by an additional power bank to be used in case of electricity outage for a certain time.

##### 3.1.1.1.1. AP1-H

The AP1-H version of AP-NURSE Home is designed to be placed under bed of a patient or client of the care center. This unit consists of the power adapter, PIR motion sensor, MQ-135 smoke sensor, light sensor, force sensor, BME 280 environmental sensor, buzzer, event button and day/night switch. The Scheme of the AP1-H version is shown in **Figure 11** and the photos of the real units in **Figure 12**, where two modifications are shown, one with power bank and the other without power bank.

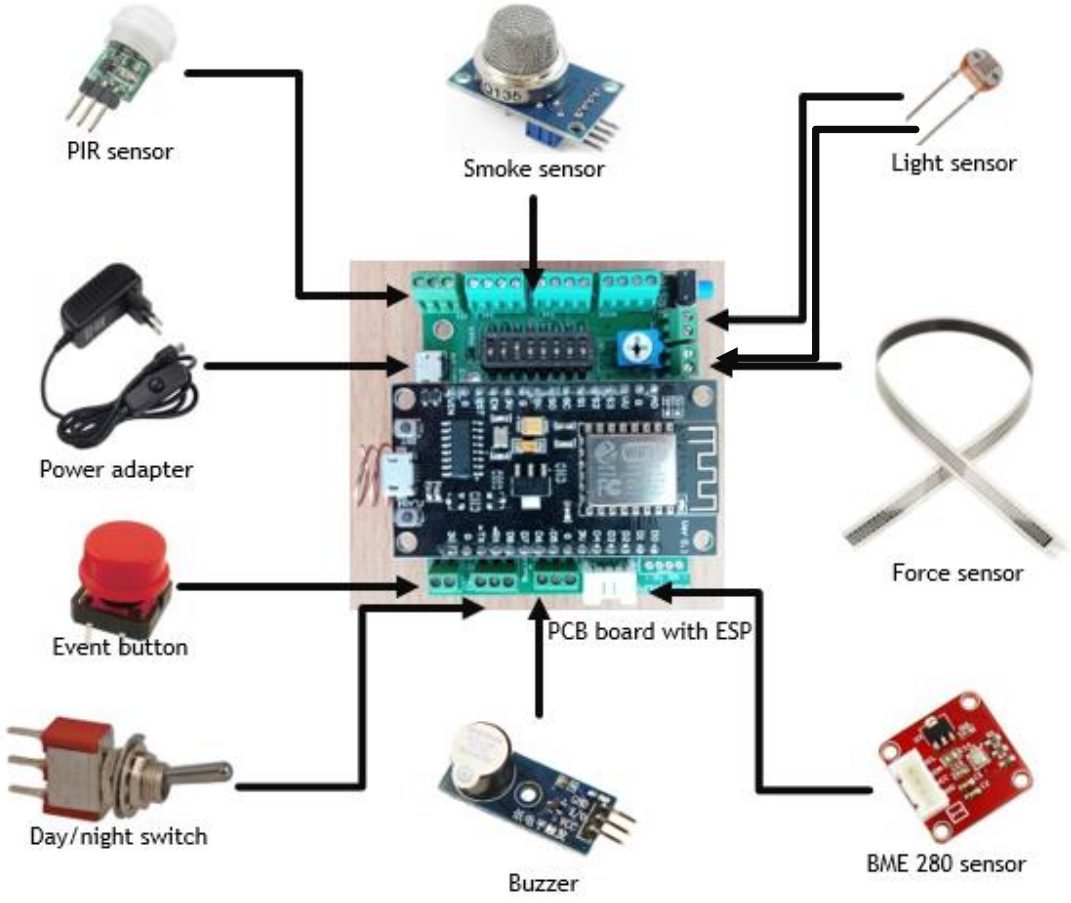
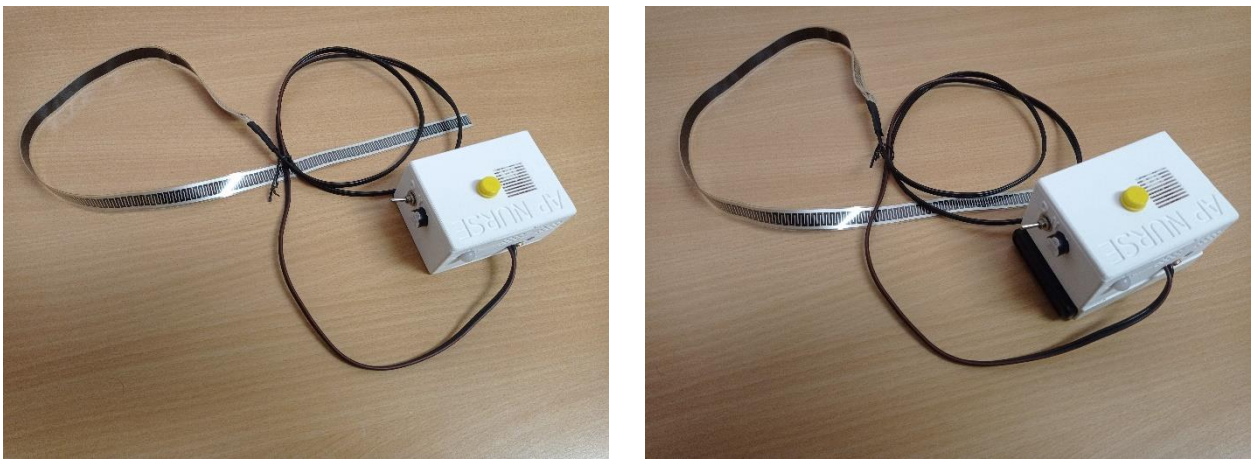



Figure 11: Final design of the AP1-H AP-NURSE version



a; withpout power bank

b; with power bank

Figure 12: Final design of the AP1-H base

#### 3.1.1.1.2. AP2-H

The AP2-H version of AP-NURSE Home is designed to be placed at the door to toilet in the room of a patient or client of the care center, alternatively to other door leading to a restricted area. This version of AP-NURSE is designed to monitor and react to a door passage. This unit consists of the power adapter, PIR motion sensor, buzzer, event button and day/night switch. The Scheme of the AP2-H version is shown in **Figure 13** and the photo of the final design of this unit in **Figure 14**.

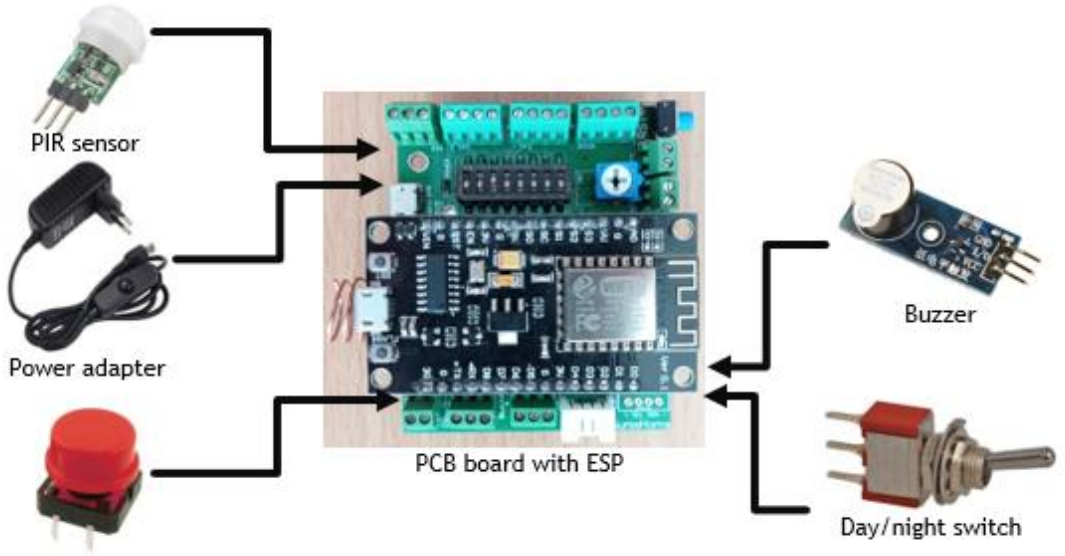



**Figure 13: Scheme of the AP2-H AP-NURSE version**


**Figure 14: Final design of the AP2-H base**

#### 3.1.1.1.3. AP4-H

The AP4-H version of AP-NURSE Home is a device designed to be located in the hallway or the common areas. This unit features motion detection. Formally, this version is identical with version AP2-H, however AP4-H version only detects motion and does not utilize the condition when client will be blocked behind the door due to any danger situation. This unit consists of the power adapter, PIR motion sensor, buzzer, event button and day/night switch. The Scheme of the AP4-H version is shown **Figure 15** and the photo of the final design of this unit in **Figure 16**.

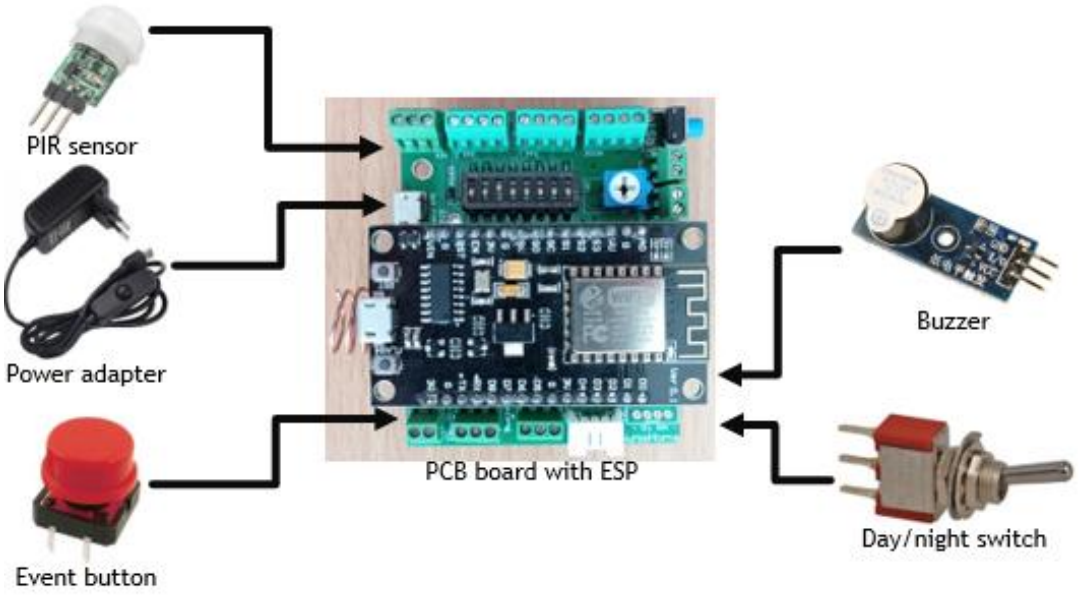



**Figure 15: Scheme of the AP4-H AP-NURSE version**

**Figure 16: Final design of the AP4-H base**

#### 3.1.1.1.4. AP6-H

The AP6-H version of AP-NURSE Home is a device designed to be placed in rooms which are used for cooking and where risk of fire is not negligible. This unit consists of the power adapter, PIR motion sensor, MQ-5 LPG sensor, MQ-135 smoke sensor, light sensor, buzzer, event button and day/night switch. The Scheme of the AP6-H version is shown in **Figure 17** and the photo of the final design of this unit in **Figure 18**.

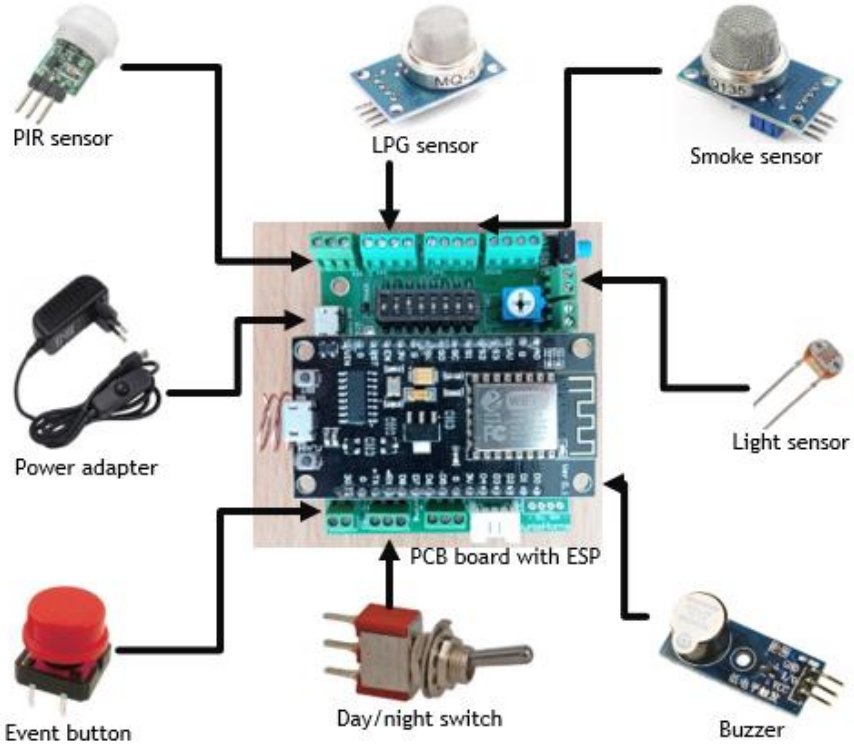



**Figure 17: Scheme of the AP6-H AP-NURSE version**


**Figure 18: Final design of the AP6-H base**

#### 3.1.1.1.5. AP7-H

The AP7-H version of AP-NURSE Home is derived from the AP1-H version and the functionality is almost the same. The localization of this units is over the client's bed. This unit consists of the power adapter, PIR motion sensor, MQ-135 smoke sensor, light sensor, BME 280 environmental sensor, buzzer, event button and day/night switch. The Scheme of the AP7-H version is shown in **Figure 19** and the photo of the final design of this unit in **Figure 20.**

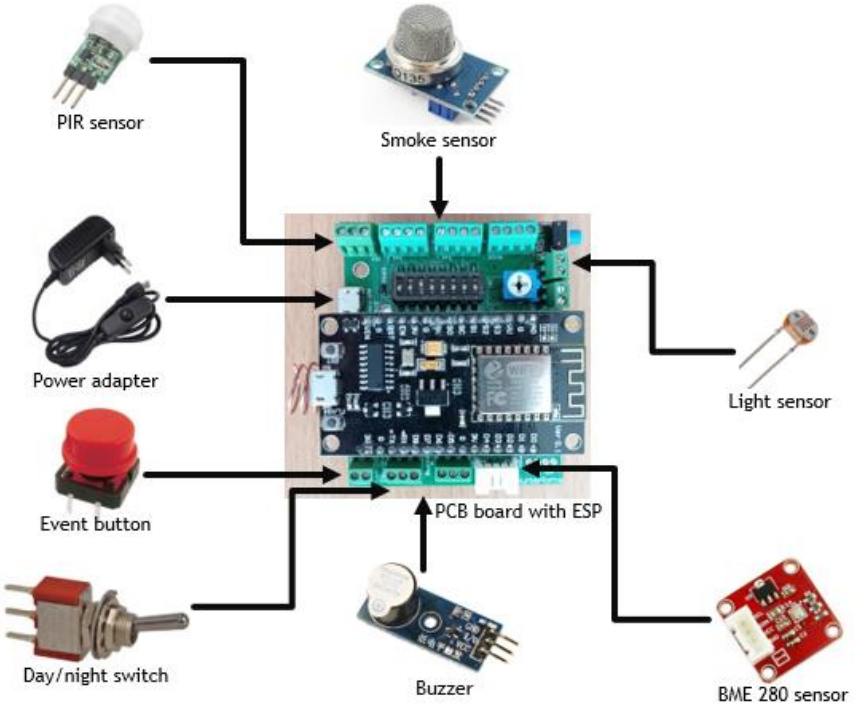



**Figure 19: Scheme of the AP7-H AP-NURSE version**

**Figure 20: Final design of the AP7-H base**

### 3.1.2. Software

The AP-Nurse Home unit is fitted with a custom built firmware based on the ESP8266 Arduino core. It is capable of handling data acquisition with the use of a variety of supported sensors. Its firmware supports configurable multi-level alert warnings triggered by external or internal events. In case of user demand, the firmware also supports data collection and remote alert notification using HTTPS requests. A more detailed description of the firmware is shown in **Figure 21.**

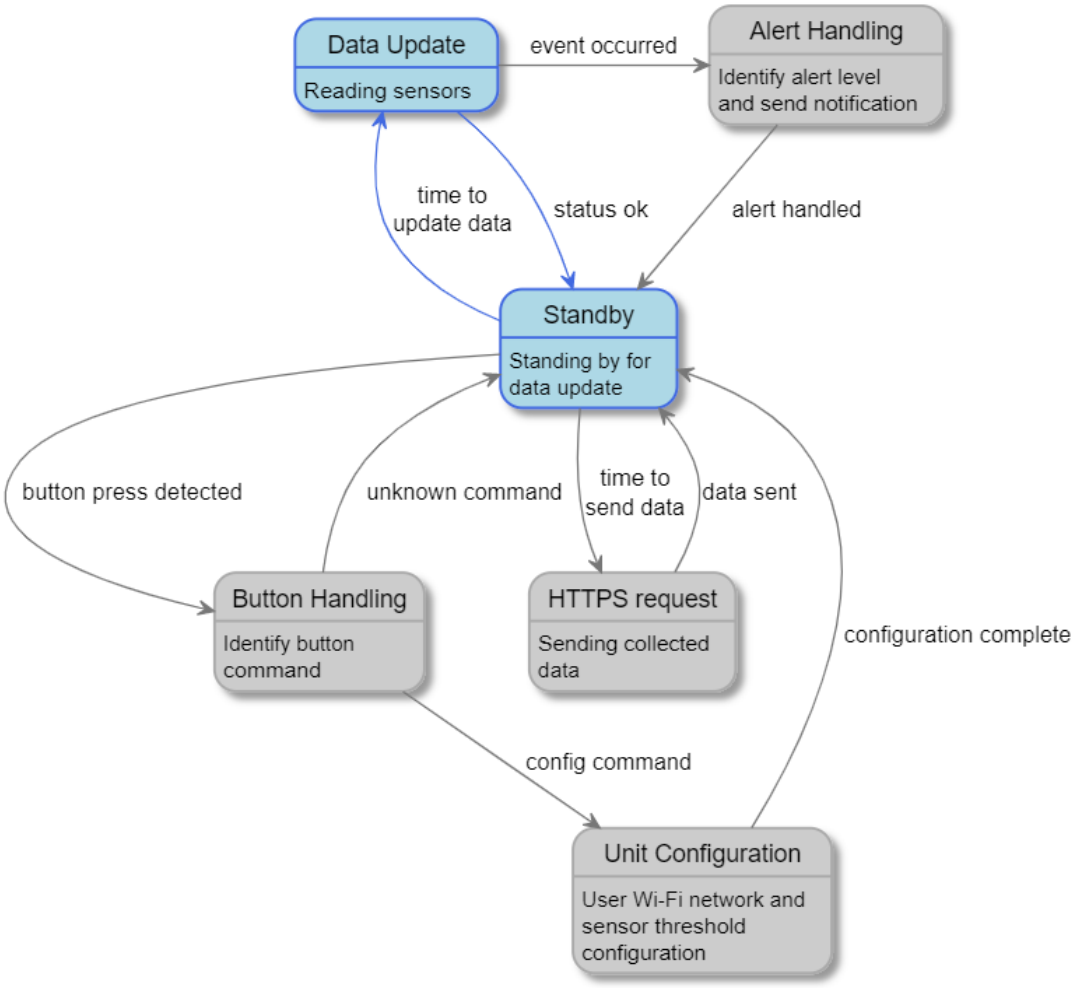
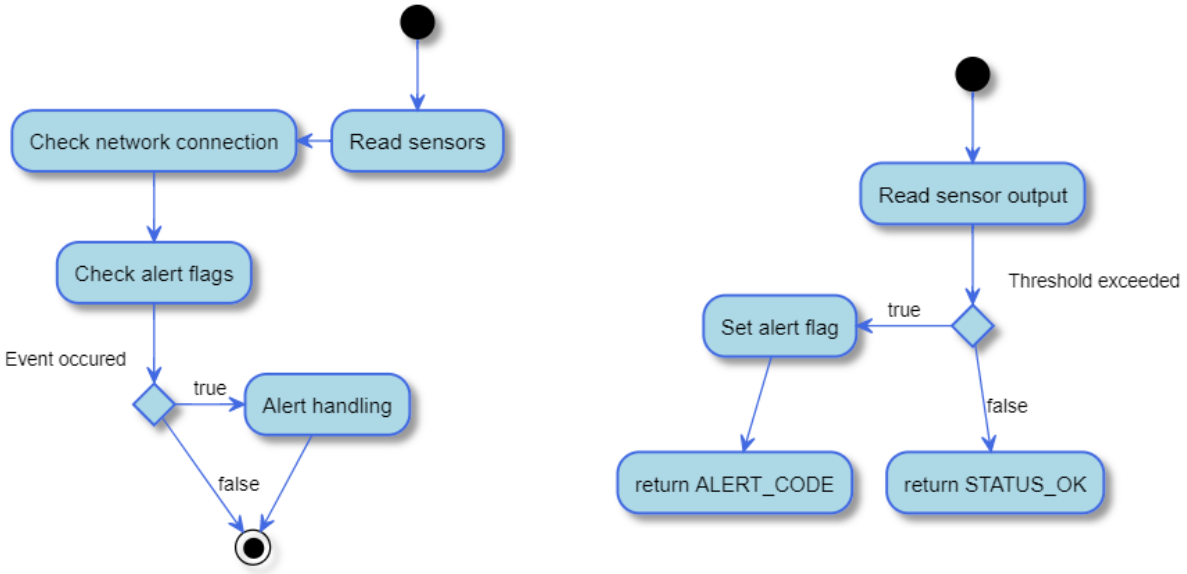



**Figure 21: AP-NURSE Home firmware state diagram**

On device boot, the ESP8266 initialises its peripherals and the AP-NURSE Home control object. After the unit is booted, the Wi-Fi network connection is in order. On successful network connection the firmware enters its main program loop. The main loop consists of two alternating states: unit stand-by and data update. During the stand-by state, the unit stands by either for a data update, button command interrupt or collected data dispatch HTTPS request. Once data update has been initiated, the firmware reads all connected sensor outputs and evaluates them. The process of data update is shown in **Figure 22.**




*a) Data update* *b) Sensor reading*

**Figure 22: AP-NURSE Home data processing diagram**

During the data update phase, the firmware also verifies the network connection. In case of a sensor value overrun or network connection loss, an alert flag is set. The alert flags are subsequently evaluated and alert handling is triggered as it is shown in **Figure 23**.

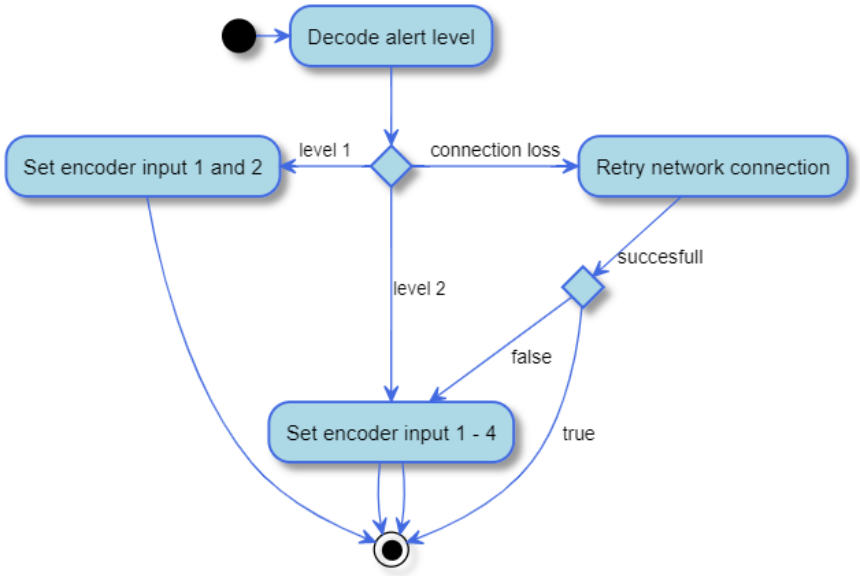



**Figure 23: AP-NURSE Home alert handling diagram**

Alert notification is provided by controlling four data inputs of the HT12E RF communication encoder that subsequently transmits the given notification. The AP-NURSE Home firmware also features a button handler able to distinguishing between multiple button commands. The present version of the firmware is however configured only to respond to a long button press. The long button press command triggers the unit configuration mode. The unit configuration uses a local server accessible through a Wi-Fi access point generated by the unit. Once connected, the unit can be configured using any standard internet browser.

### 3.1.3. Casing

The AP-NURSE Home casing was designed to cover and secure the hardware and to position sensors and buttons. During the CAD model development, the main priorities were mechanical stability, compactness, and the possibility to print with various types of 3D printers easily. The design provides easy access to all controllers, sensors, and other electronic parts. The top cover is designed as a press & click system. All frequently used controllers are accessible from the outside of the casing box. The positioning of the buttons, sensors, and other electronic parts is designed to eliminate the wiring length. The main PCB board is fixed by the screws. Other parts are fixed by the pressure of openings and by glue. From the bottom side of the casing the slots for the battery holder's fixation using the press & click system are located. The Design – Print – Test loop process was used to develop the final casing. The set of AP-NURSE Home casings include the *base* (**Figure 25**), the *wearables* (**Figure 27**) and the *batery holder* (**Figure 29**).

#### 3.1.3.1. AP-NURSE Home base

During the development of the AP-Nurse Home base casing, eight iterations were applied (**Figure 24**). After each CAD development, the model was printed and tested. The changes were made according to the findings from the testing and according to the hardware changes.

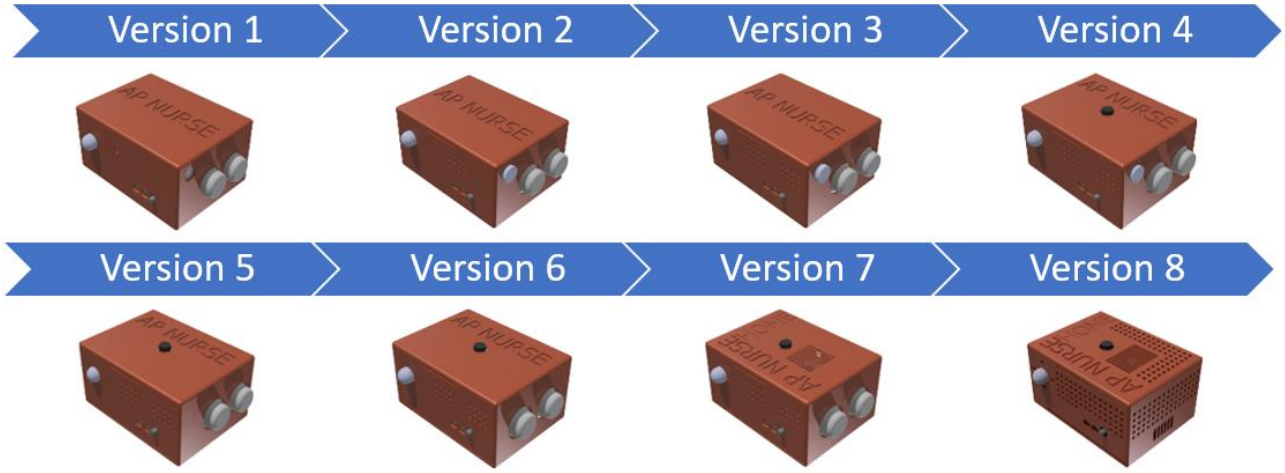



**Figure 24 Iterations during development of the casing for AP-NURSE Home base.**


1) gas sensors, 2) reset button, 3) cooling holes, 4) opening for tensometer, 5) PIR sensor, 6) opening for temperature and humidity sensor, 7) button, 8) day/night switch, 9) buzzer, 10) micro USB openings.

**Figure 25 Casing for AP NURSE Home base**

### 3.1.3.2. AP-NURSE Home wearables

During the development of the casing for the wearables, four iterations were applied (**Figure 26**). After each CAD development, the model was printed and tested. The changes were made according to the findings from the testing and according to the changes of the wearable.

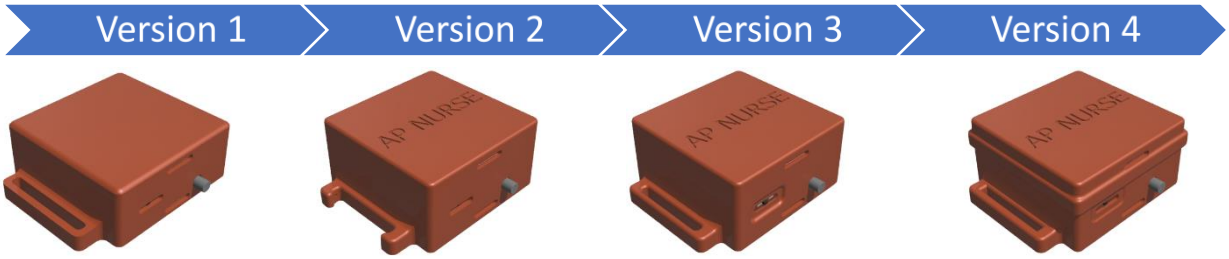



**Figure 26 Iterations during the development of thee casing for wearables**

The final casing is equipped with the holes for the buttons, inside slot for the antenna and with the wearable slot (**Figure 27**). The final casing consists of three parts – bottom cover, middle part, and top cover.


**Figure 27** Casing for **AP NURSE wearables**

**1) wearable slot, 2) switch button, 3) antenna slot, 4) click slot, 5) reset button.**

### 3.1.3.3. AP-NURSE Home battery holder

During the development of the AP-NURSE Home abatery holder, six iterations were applied (**Figure 28**). After each CAD development, the model was printed and tested. The changes were made according to the the testing and the battery changes. The battery holder is also used for AP-NURSE Care M5Stack units.


**Figure 28 Iterations during development of the holder.**

The final holder model is equipped with the screw holes for fixation of the holder on the wall, slot for fixation of the central unit, and the power bank's slot (**Figure 29**). User friendly “press & click” system was developed for powerbank fixation as well as for AP NURSE Home/AP NURSE Care fixation.


1) power bank, 2) cable cover, 3) slot for connection with AP NURSE Home/Care.

**Figure 29 AP NURSE holder**

## 3.2. AP-NURSE Care M5stack

### 3.2.1. Hardware

The hardware configurationof all AP-NURSE Care M5Stack devices is created using the M5Stack modular stackable paltfrom, as described in chapter 2.4.2. Ech configuration consists of the M5StickC Plus unit (called base), batery holder or rechargeable 18650 C HAT and a couple of sensors, regarding the given version. In order to fulfil the widest possible spectrum of use cases in care centers, AP-NURSE Care has to be adapted into a set of configurations of the base and the sensors. Based sed on specific needs of potential users, four versions of the AP-NURS Care M5Stack version. The next section describes the configuration of each AP-NURS Care M5Stack version.

#### 3.2.1.1. AP-NURSE Care M5stack versions

##### 3.2.1.1.1. AP1-M

The AP1-M version of AP-NURSE Care is designed to to be placed under the bed of a patient or a client of the care center. This unit consists o the base, the battery holder and the BME680, PIR and FSR sensors. The Scheme of the AP1-M version is shown in **Figure 30** and the photo of the final design of this unit in **Figure 31**.

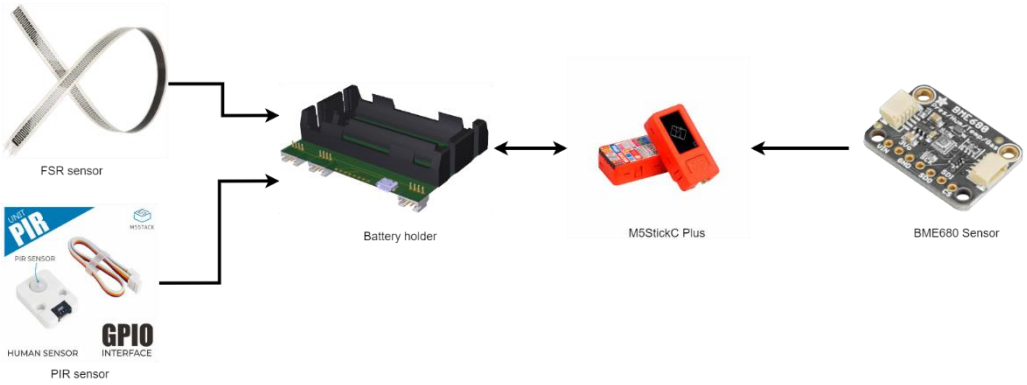



**Figure 30: Scheme of the AP1-M AP-NURSE version**

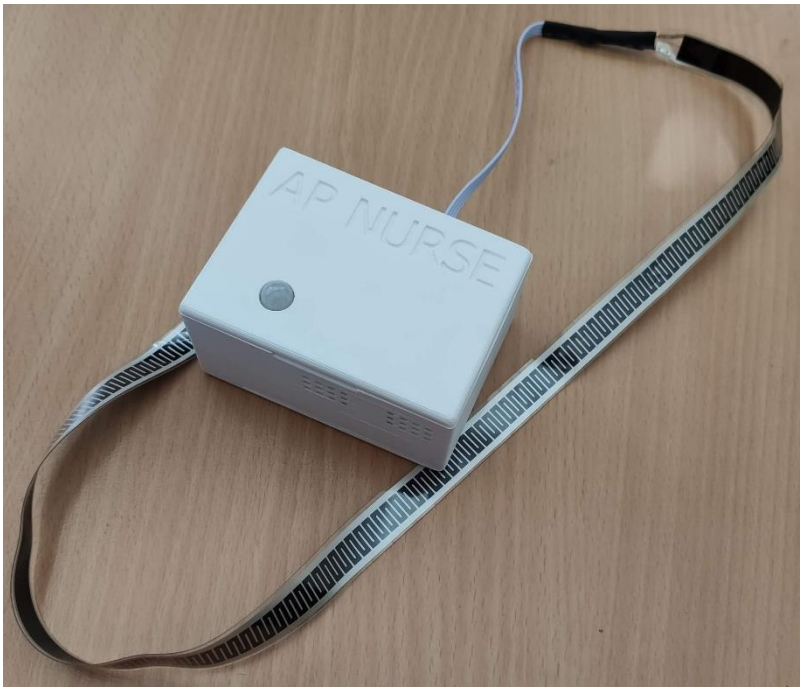



**Figure 31: Final design of the AP1-M base**

#### 3.2.1.1.2. AP2-M

The AP2-M version of AP-NURSE Care is designed to to be placed at the door to toilet in a room or other door leading to a restricted arrea. This version of AP-NURSE is designed to monitor and react to a door passage. This unit consists o the base, the 18650 C HAT and the ToF sensor.The Scheme of the AP2-M device is shown in **Figure 32** and the photo of the final design of this unit **Figure 33**.


**Figure 32: Scheme of the AP2-M AP-NURSE version**

**Figure 33: Final design of the AP2-M base**

#### 3.2.1.1.3. AP4-H

The AP4-M version of AP-NURSE Care is a device designed to be located in the hallway or the common areas. This unit features motion detection. This unit consists o the base, the 18650 C HAT and the PIR motion sensor.The Scheme of the AP4-M version is shown in **Figure 34** and the photo of the final design of this unit in **Figure 35**.


**Figure 34: Scheme of the AP4-M AP-NURSE version**

**Figure 35: Final design of the AP4-M base**

#### 3.2.1.1.4. AP6-H

The AP6-M version of AP-NURSE Care is a device designed to be placed in rooms, which are used for cooking and where the risk of fire is not negligible. This unit consists o the base, the Batery holder, as well as PIR, BME 680 and ligh sensors.The Scheme of the AP6-M version is shown in **Figure 36** and the photo of the final design of this unit in **Figure 37**.

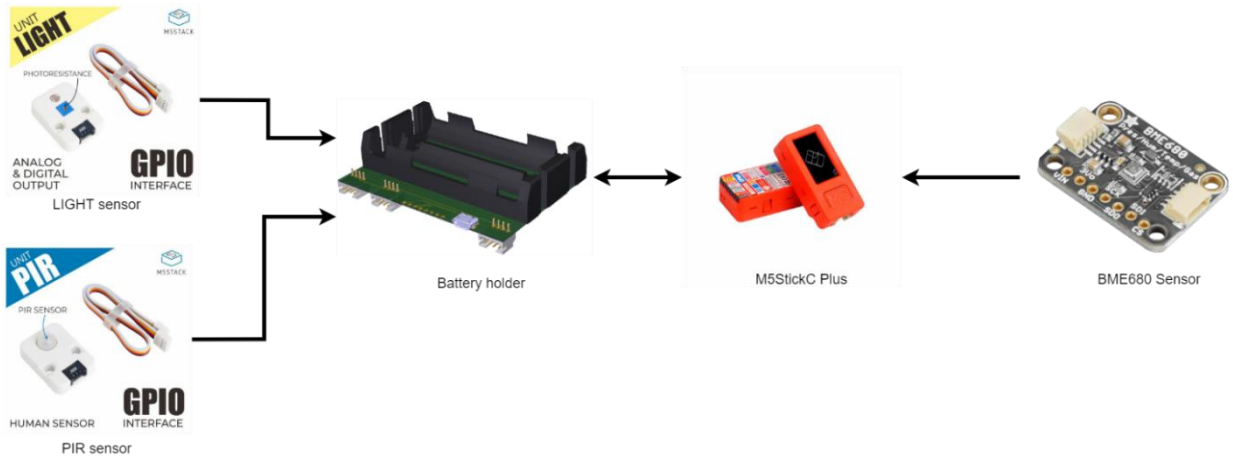



**Figure 36: Scheme of the AP6-M AP-NURSE version**


**Figure 37: Final design of the AP6-M base**

### 3.2.2. Software

The AP-NURSE Care M5Stack firmware is based on the ESP32 Arduino core. The latest version of the firmware supports OTA Programing (3.2.2.1) for convenient unit software upgrades. AP-NURSE Care M5Stack is capable of handling data acquisition with the use of a variety of supported sensors. The system supports configurabledata advertisement intervals and regimes. A more detailed description of the firmware is shown in **Figure 38** and **Figure 39**.

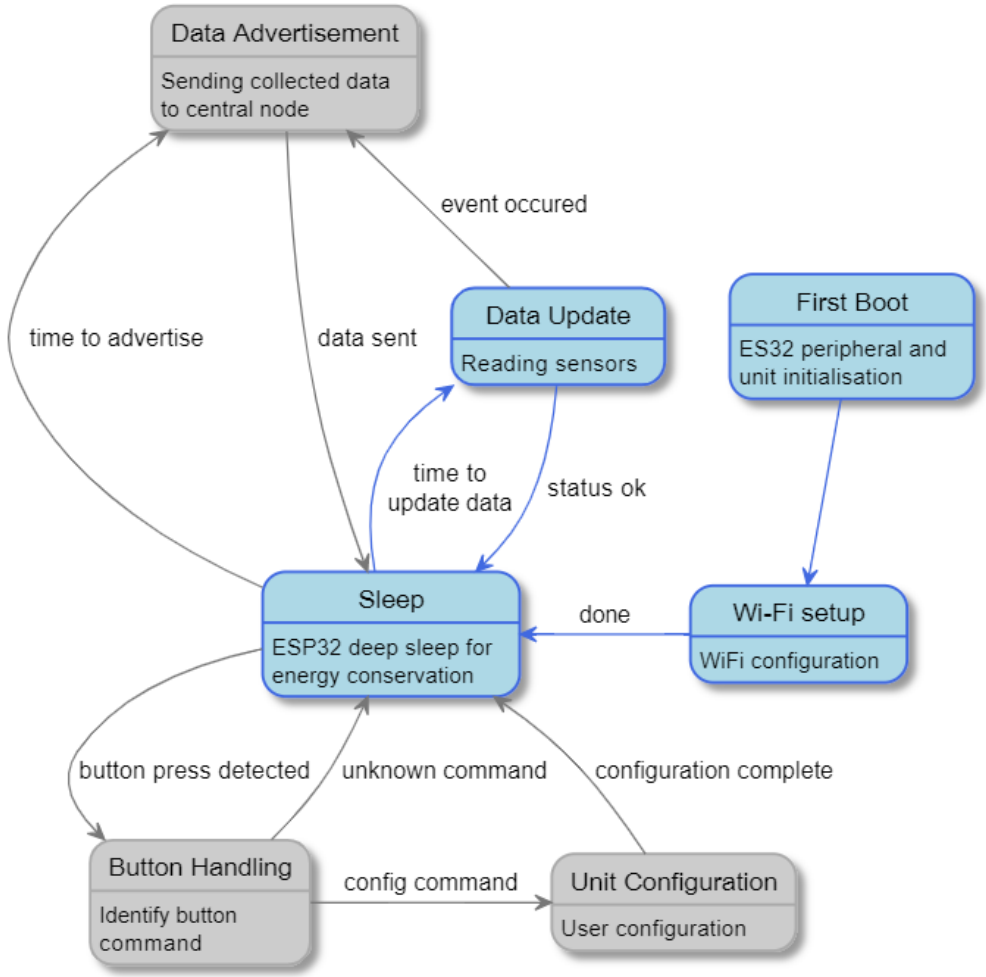



**Figure 38: AP-NURSE Care M5Stack firmware state diagram - RTC timer triggered wake-up/data swing triggered advertisement**

The unit firmware manages its main operation loop. After the units first boot, a user Wi-Fi provisioning configuration is in order. Once complete the unit enters its main operation loop. The RTC timer of the ESP32 is configured to periodically wake up the device to update measured data. If a significant meassuremed data swing is detected measured data is advertised to the information system. Data advertisement also occurs in periodic intervals, in between which the measured data are stored in the devices flash memory, bypassing the need to advertise during every wake-up cycle, significantly reducing device power consumtion.

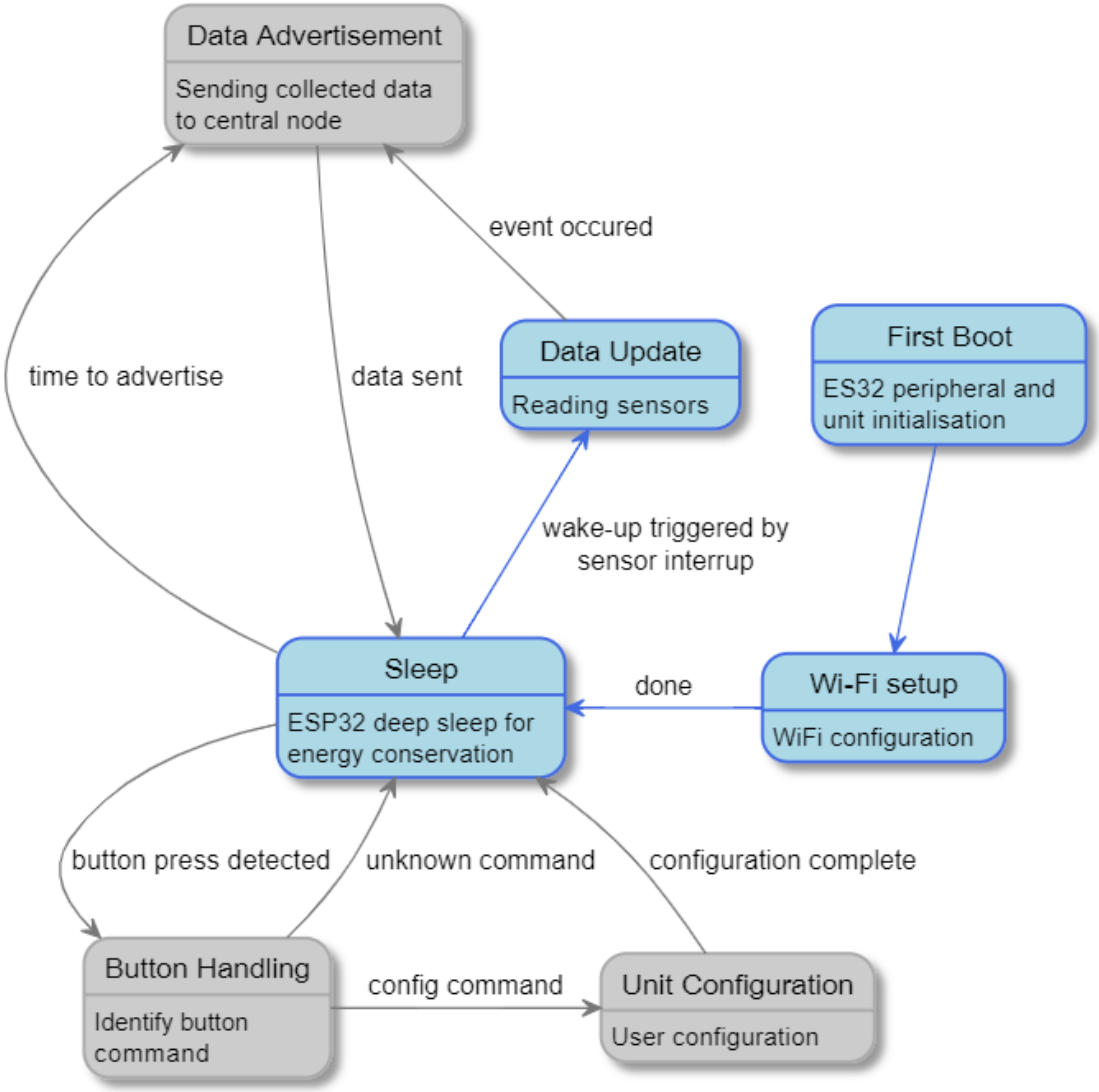



**Figure 39: AP-NURSE Care M5Stack base firmware state diagram Interrupt triggered wake-up/advertisement**

Even further power conservasion was achieved in the FW of the AP4-M unit using the PIR motion sensor output as an interrupt for ESP32 wake-up. This device, however, also features periodic data advertisement for so called “deadbeat” (to let the information system know that it is alive and operational) also to supply the system with information about its battery level. All advertised data is evaluated by the information system based on the logic described in Table 3 of D.T.2.2.4 [3] .

The configuration of a M5Stack unit is triggered by a long button press. As seen in the case of AP-NURSE Home unit, configuration uses a local server accessible through a Wi-Fi access point generated by the unit. Once connected the unit can be configured using any standard internet browser. More information on the data collection and the IT system can be found in chapter 3.4.

### 3.2.2.1. OTA programming

To avoid incompatibility issues with the drivers of lopcal computers used for testing the AP-NURSE Care M5Stack devices, OTA (over the air) programing can be implemented that enables remote firmware update via a Wi-Fi network, circumventing most, if not all, driver incompatibilities. This feature offers the hardware develpmnet team to connect to a secure HTTPS web server created by any AP-Nurse Care module and upload the latest version of its firmware. The OTA firmware upgrade, moreover, is a convenient means to provide device firmware updates to clients once the system is operational in their istitution, without the need the presence of a developer. Screans of the OTA FW upgrade are shown in **Figure 40** and **Figure 41**.

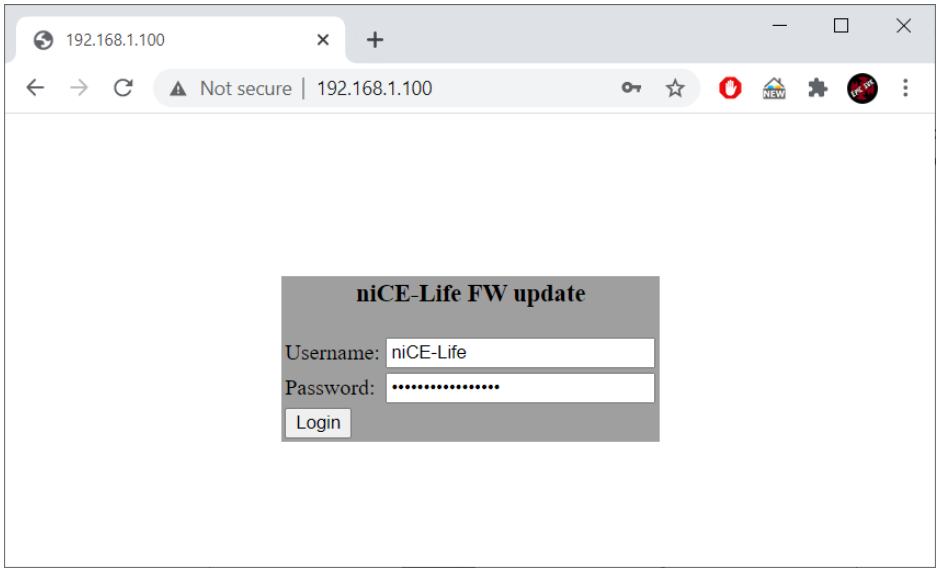



Figure 40 - OTA FW upgrade webserver login screen

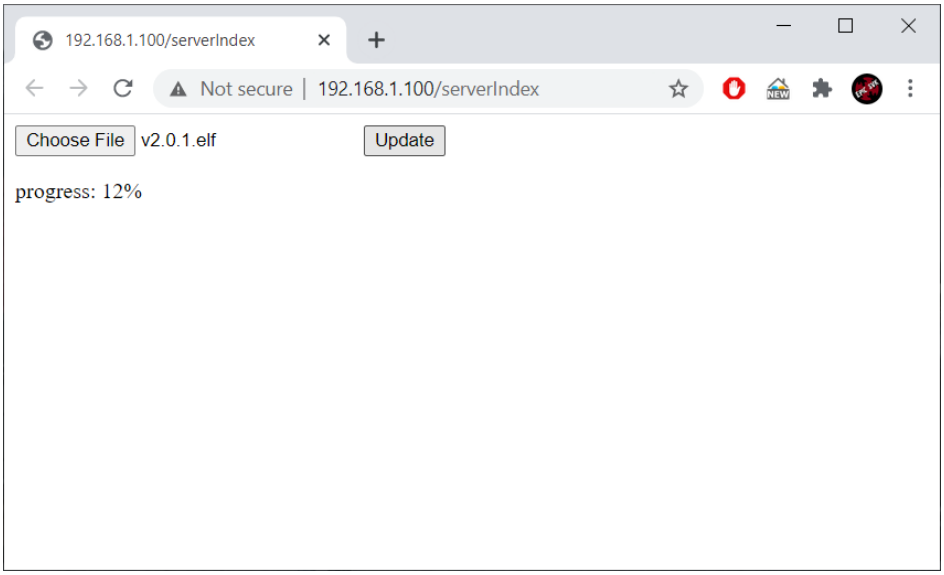



Figure 41 - OTA FW upgrade in progress

### 3.2.3. Casing

The AP-NURSE Care casing was designed for the AP1-M and AP6-M versions. The idea was to cover and secure hardware and position sensors and buttons (**Figure 42**). During the CAD model development, the main priorities were mechanical stability, compactness, and the possibility to print with various types of 3D printers easily. The design provides easy access to all controllers, sensors, and other electronic parts. The top cover is designed as a press & click system. All frequently used controllers are accessible from the outside of the casing box. The positioning of the buttons, sensors, and other electronic parts is designed to eliminate the wiring length. Electronic components are fixed by the pressure of the casing box openings and by glue. From the bottom side of the casing are located the holes for the fixation of the battery holder using the press & click system. The Design – Print – Test loop process was used to develop the final casing. The AP-NURSE Care casing consists of the casing for the AP-NURSE Care M5Stack base (**Figure 43**). The AP-NURSE Care casing is compatible with AP NURSE holder (**Figure 29**).

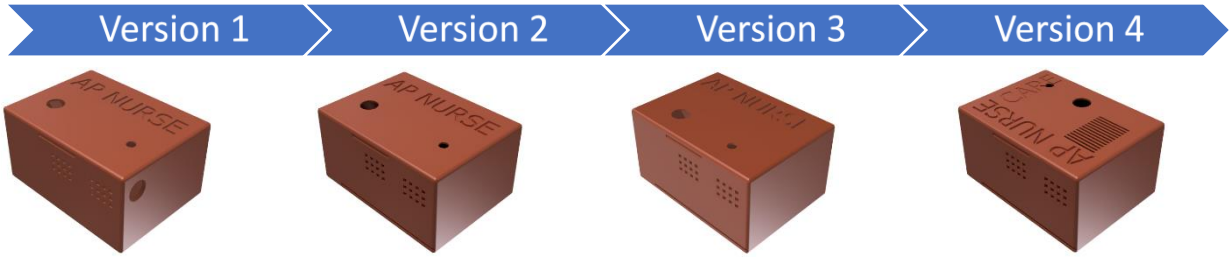



**Figure 42 Iterations during development of the casing for AP-NURSE Care M5Stack**

The final casing is equipped with the slot for fixation of the power bank holder, holes for the sensors and buttons, and openings for cooling the electronics (**Figure 43**). The final casing consists of two parts – the bottom part and top cover.


**Figure 43 AP NURSE Care M5Stack casing**

**1) cooling holes, 2) opening for VOC, temperature, humidity and pressure sensor, 3) Opening for PIR sensor, 4) Opening for time of light sensor, 5) opening for tensometer, 6) opening for power charging, 7) opening for micro USB.**

## 3.3. AP-NURSE Care Waspmote

### 3.3.1. Hardware

AP-NURSE Care Waspmote version is based on the Waspmote WiFi PRO base, which include Waspmote v15 base board and WiFi PRO module. This configuration is able to monitor the environment via multiple sensors attached and send data via local WiFi network. The hardware components and the technical descriptions of components can be found in D.T2.2.2 [1] and D.T2.2.3 [2]. Compared to the original design, proposed air quality sensors were replaced by the MQ5 and MQ135 sensors which were tested and are part of the AP-NURSE Home versions. Rest sensor are same as were described in previous reports. After the testing compatibility all of the chosen components, the circuit schematics were designed for the AP-NURSE Care versions. The final version of the AP-NURSE Care W is shown in **Figure 44**.

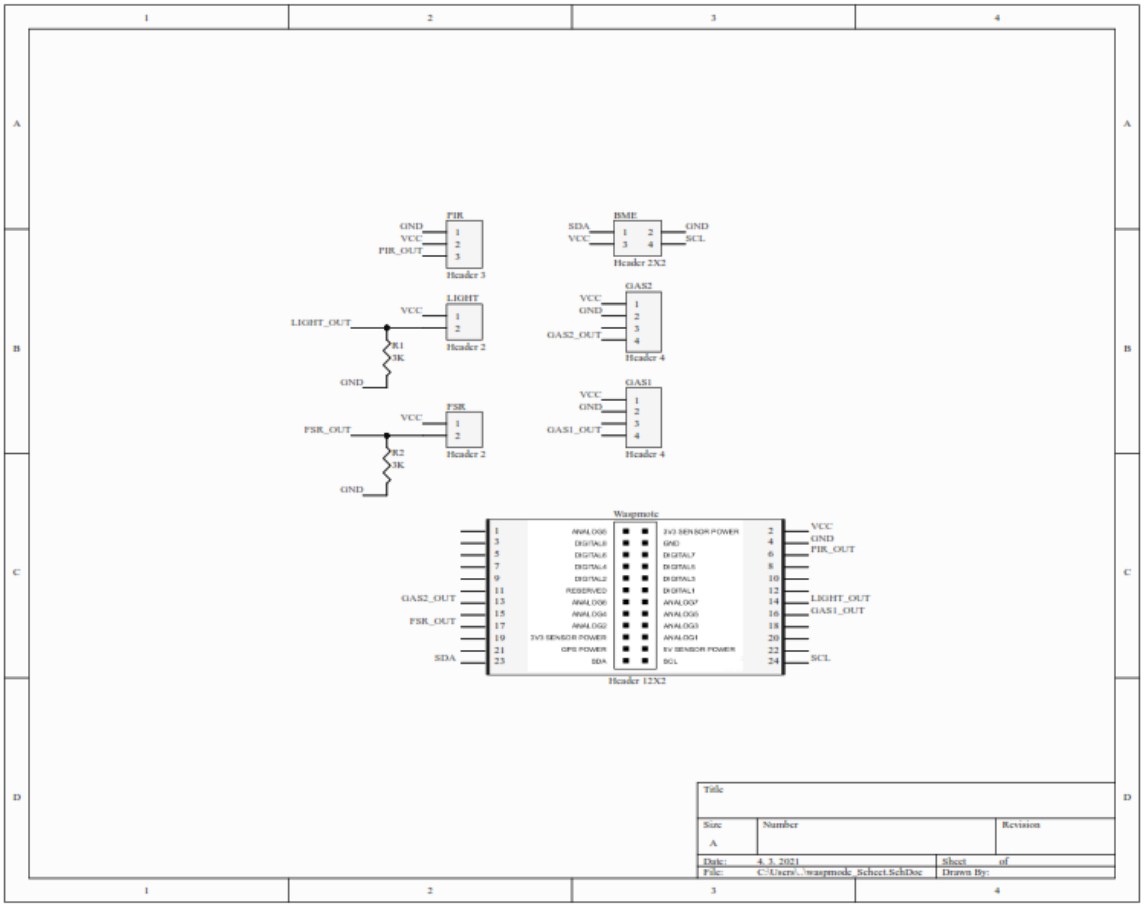



**Figure 44: Final AP-NURSE Care Waspmote schematics**

Based on this scheme, prototype PCB circuit boards is currently under development for manufacturing. The sensors are connected to the board directly or by extending cables. In cases where the fast response to clients motion is required or long therm battery operation is planned, the PCB circuite can be replaced by Event board. Power button and WiFi antenna is mounted on the casing with extension cables. The power supply of the AP-NURSE Care Waspmote base may be direct from the wall outlet or from battery.

#### 3.3.1.1. AP-NURSE  Care Waspmote versions

##### 3.3.1.1.1. AP1-W

The AP1-W version of AP-NURSE Care is designed to be placed under the client's bed. This unit consists of the Waspmote WiFi PRO platform, the Battery, MQ5 and MQ135, LDR sensor, the BME280, PIR and FSR sensors.The Scheme of the AP1-W version is shown in Figure 45 and the photo of the working version of the casing and the unit configuration is shown in **Figure 46**.

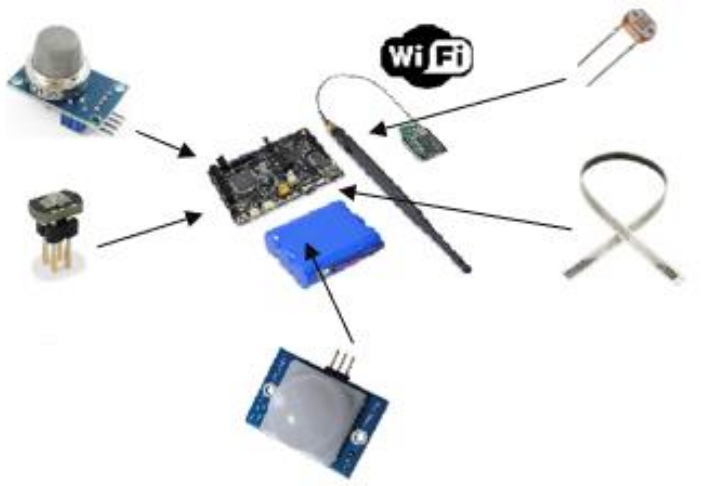



**Figure 45: Scheme of the AP1-W AP-NURSE version**

**Figure 46: First prototype of the AP1-W base**

#### 3.3.1.1.2. AP8-W

The AP8-W version of AP-NURSE Care is designed to be placed on the client's wheelchair or any equipment where it is required to monitor and prevent fall of the patient or client of the care center. This unit consists of the Waspmote WiFi PRO platform, the Battery, Buil-in accelerometer and FSR sensors. The scheme of the AP8-W AP-Nurse version is shown in **Figure 47**.


**Figure 47: Scheme of the AP8-W AP-NURSE version**

### 3.3.2. Software

The AP-Nurse Care Waspmote unit is fitted with a custom built firmware based on the Waspmote API. It is capable of handling data acquisition with the use of a variety of supported sensors. The firmware supports data collection and periodical notification about current sensor states using HTTPS requests. In case of user demand, the firmware also supports alert warnings triggered by external events. The firmware state diagram is shown in **Figure 48**.

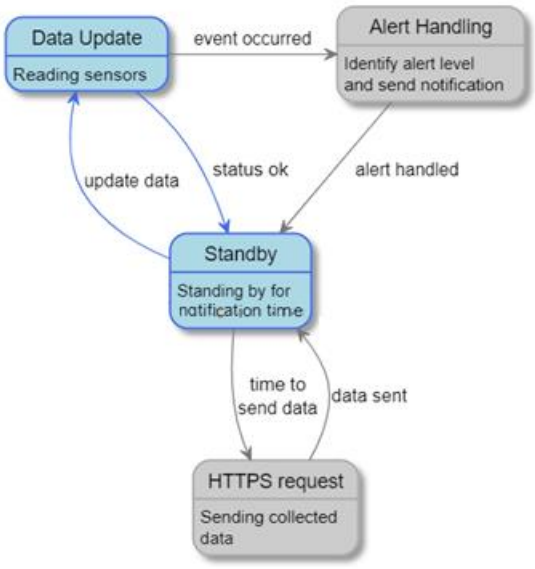



**Figure 48: AP-NURSE Care Waspmote firmware state diagram**

On device boot, the Waspmote initialises all peripherals. After the unit is booted, the Wi-Fi network connection is established and communication with the Meshlium is checked. After successful network connection the firmware enters its main program loop. The main loop consists of two alternating states: data update and data sending. In each loop the firmware reads all connected sensor outputs, evaluates them and update data package variables. During the data sending state, frames from the data package are prepared and the HTTPS request is sent. Data sendings is initiated based on pre-defined time interval (every 30 sec, 60 sec., …).

Prepared message frame includes uniqe CA certificate corresponding to the used Meshlium. Due to the HTTPS length restrictions, sesnsors' data package is splitted into two separate frames, where Meshlium is able to correctly parse thees frames and can store them in the internal MySQL database. Moreover all HTTPS messages are encrypted using AES 128. Synchronization of MySQL Database with external service is currently under development with TLR level 5.

As an additional functionality, all sensor data may be sent by HTTP requests to the AP-NURSE Care information system.

### 3.3.3. Casing

Casing for AP-NURSE Care Waspmote is currently in development. The design will be included in the updated version of this report.

## 3.4. Data collection - IT system

On the specification and features of the AP-NURSE Care information system and user interface was elaborated in the report DT2.2.3 [2].

The security of the system was improved substantialy since the last report. Last core of the information system used an RSA encryption based password authentication using a key generated by a pseudorandom function, specifically the password-based key derivation function 2 (PBKDF2). This, however posed a risk of compromise in a case of an attacker were to gain acces to the generated key, since all the device requests were authenticated using a single, stable key. The new core of the information system provides device and user authentication using eliptic curve cryptography (ECC). This way, on device creation a pair of elyptic curve keys are generated. A private one, used for electronic signature generation (these signatures are subsequently used for request authentication), and a public one used for the digital signature validation. The public key is then registered in the information system database and is later used for the verification of the device requests authenticity. The private key never leaves the device. Hence, should the shared public key be compromised, the attacker has no acces to the information system, for without the private key, no valid digital signature can be generated.The user interface features a device list, where all devices regitstered under a user account can be found. From here an individual device detail screen is accessible, containing all the devices relevant information (name, type, mac address, measured data, etc.).

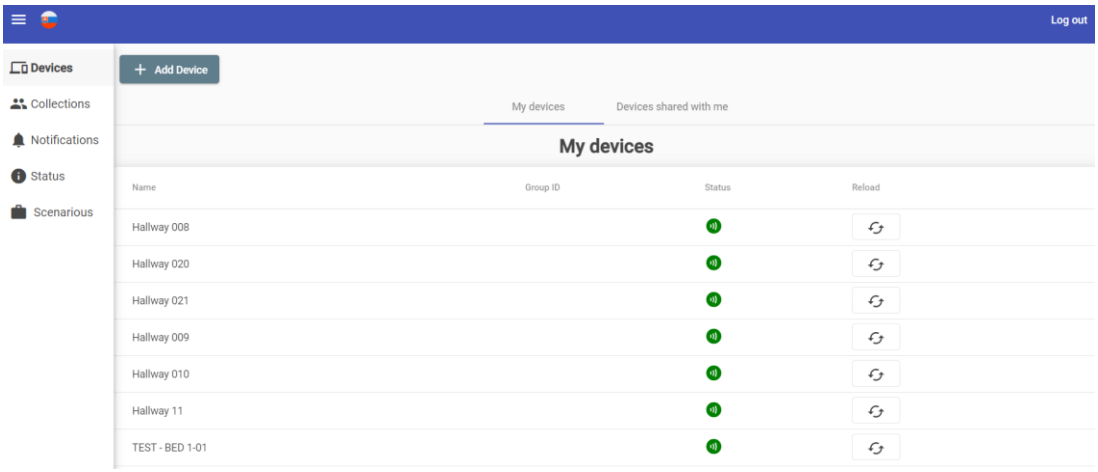



Figure 49 - Device list

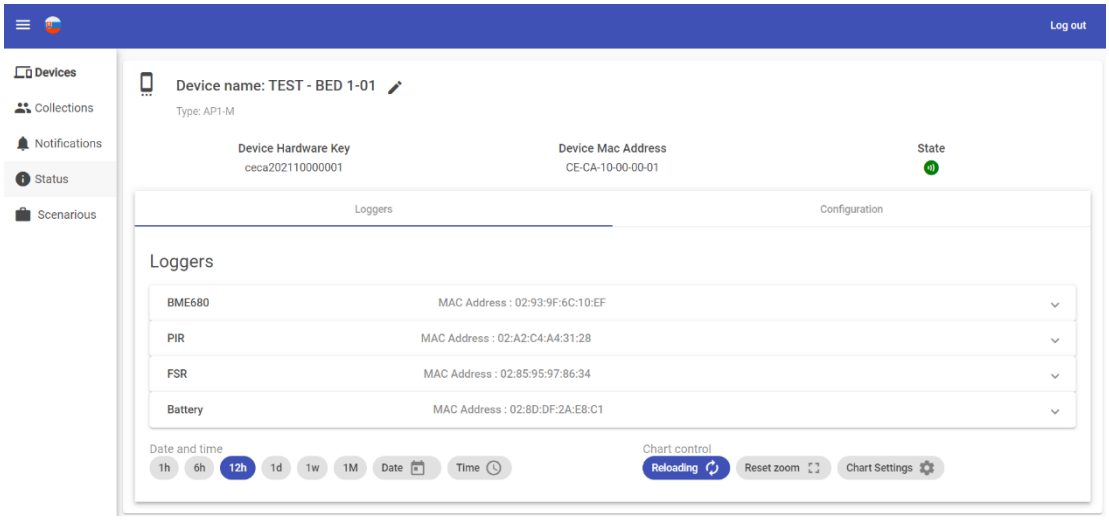



Figure 50 - Device detail


**Figure 51 – IS data preview - Temperature**

The user interface allows the creation of device "collections" enabling device association to groups, each of which can be assigned their individual alerts. Examples of device and data collection, with configured notifications are shown in **Figure 52 - Figure 55**.

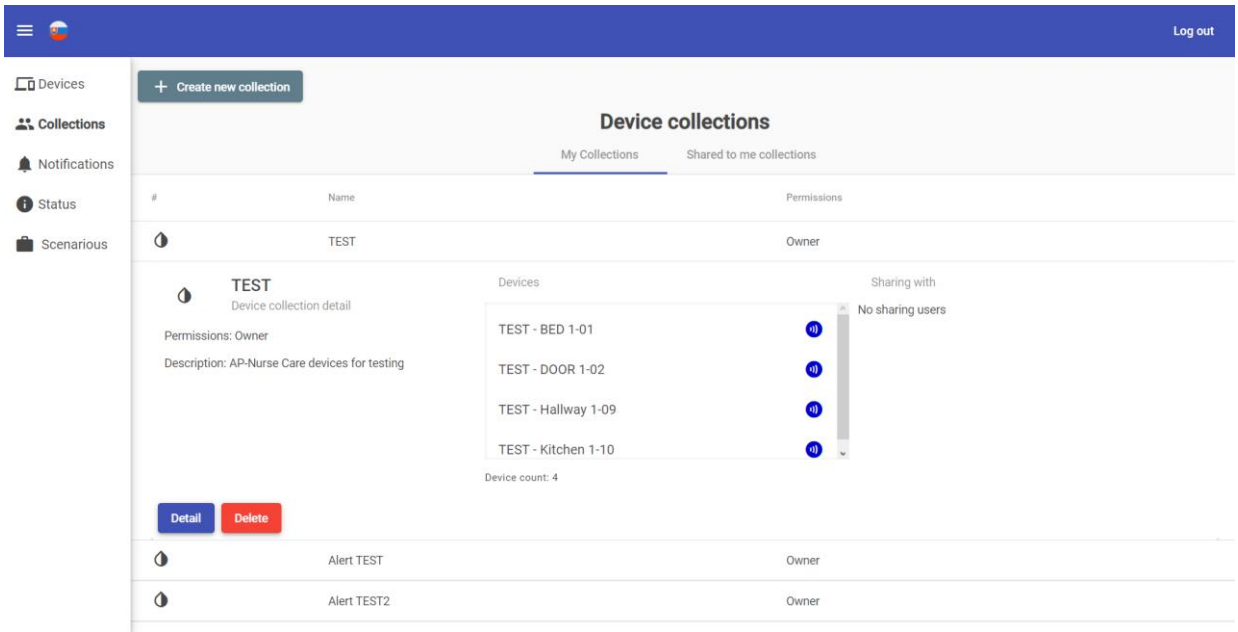



**Figure 52 – Device collections tab**

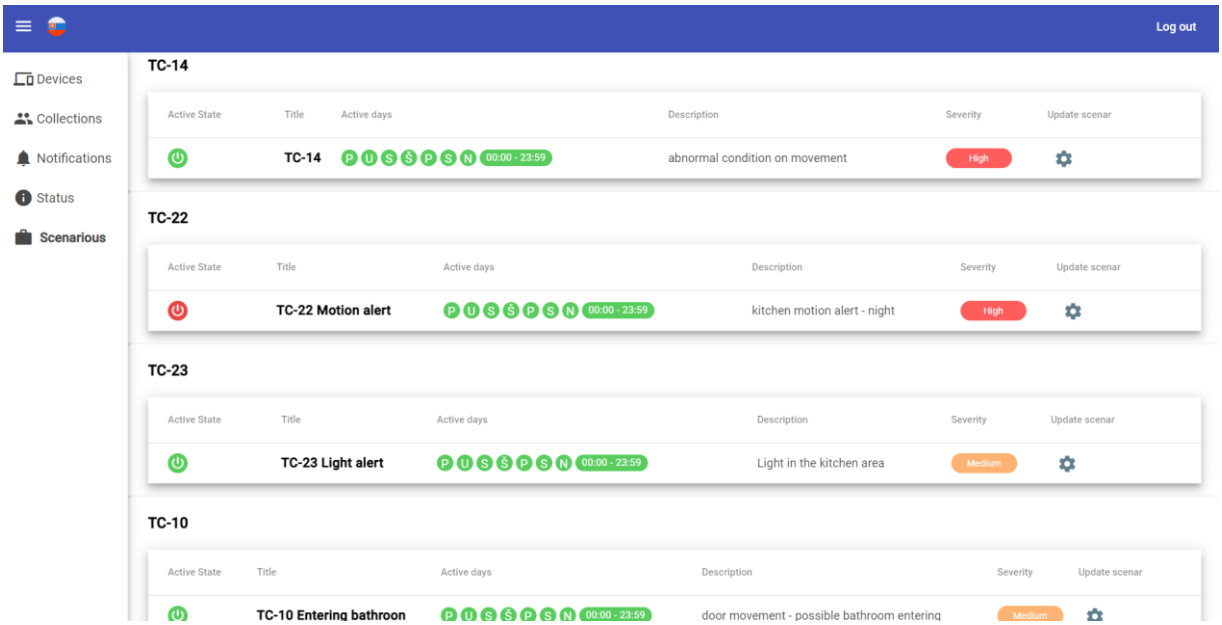



Figure 53 - Notification setup

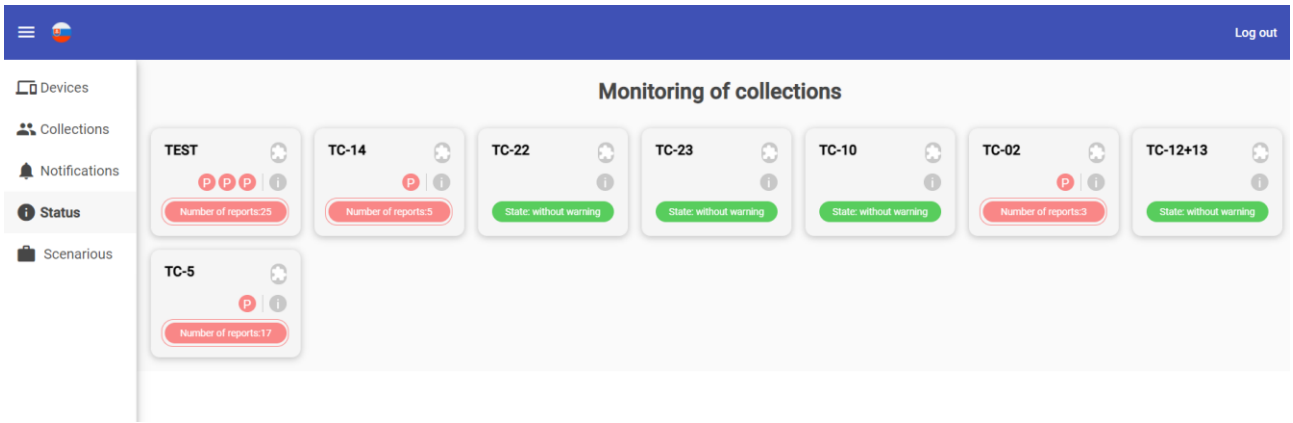



Figure 54 - Collection status

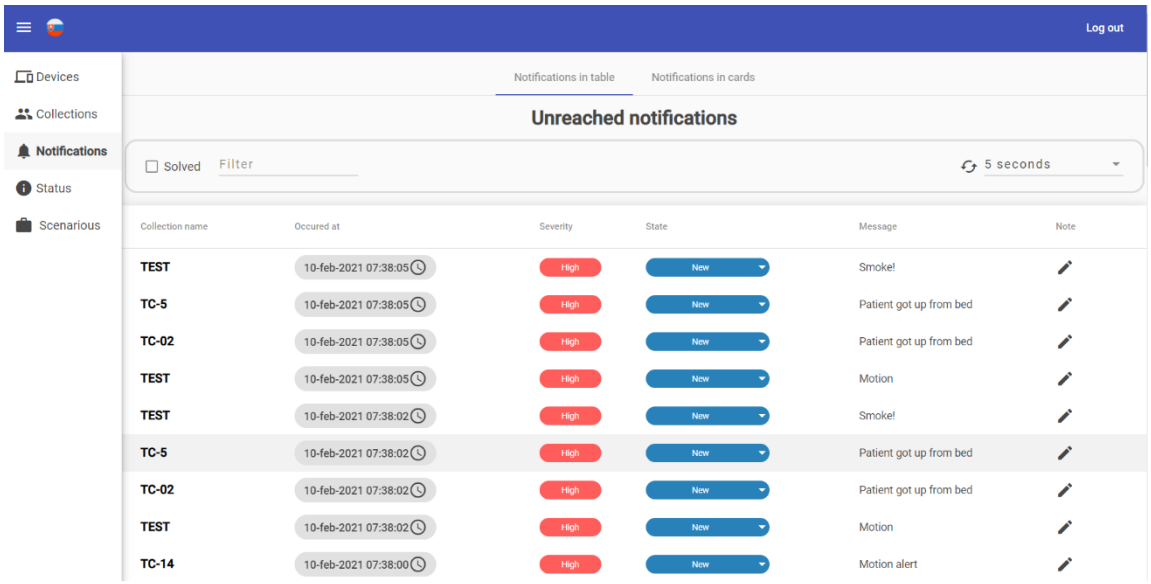



**Figure 55 - Notifications**

# 4. AP-NURSE laboratory testing

## 4.1. Testing environment

Both systems, AP-NURSE Home and Care, are designed to be deployed in an interior and mainly in rooms where patients spend the most of their time. To test all sensors, micro-controllers, communication modules, their performance in real environment and also not to bother the clients and the staff of care centres with thorough testing routines, special testing room was designed and prepared at STU. In a phase of laboratory testing, it is very important to gain practical experience with all prototypes and to validate the prepared scenarios or test cases. Therefore, the testing must go through all initialization events, event chains, predictable or non-predictable sequences of the events, proposed caregivers' responses, and should validate the thresholds and also the ability of the whole system to operate in case of multiple events. Thus the testing environment has to be as similar as it is possible to the real testing site. According to the project schedule, the first testing was carried out locally at STU. If necessary, based on the achieved results, the testing may also continue on-site, at the selected care centre in uninhabited rooms. The main features and equipment of the testing room are as follows:

- Adjustable bed (can be used as a sofa)
- Open and lockable cabinets
- Armchair and office chairs (spatial barriers, wheelchair)
- Tables (caregiver monitoring desk)
- Washbasin
- Shelves (with good or worse access)
- Basic household appliances (available in Care centres – coffeemaker, radio, TV)
- Power sockets (limited number and access)
- Openable Window
- Sunblind (to simulate day/night cases)

Photos of the STU testing environment can be found in D.T2.2.3 [2] and D.T2.2.4 [3].

## 4.2. Testing methodology

The testing procedure developed for the AP-NURSE Home and Care devices consist of the following three phases:

- Function tests
- Test cases
- Sensor sensibility tests

In addition, for the AP-NURSE Care Waspmote platform, that is in a slight delay compared to other platforms, a special preliminar tests were prepared and performed according to the current development stage.

## 4.2.1. Function tests

### 4.2.1.1. AP-NURSE Home

Several functional tests were designed to be performed on every AP-NURSE Home device. The aim of the selected tests is to verify the basic functionality and performance of the developed device. These tests are based on the events according to schemes presented in **Figure 56 - Figure 59**. There are four basis event flow tests from which 24 function test were derived. All function test are performed at least 10 times and the results are evaluated in the test protocols. In the event flow charts, the following marking are used:

- Grail infill box – functionality of the base
- White infill box – functionality of the wearables

In the following section, the four AP-NURSE Home event flow tests are briefly explained.

**Event flow test 1**

Event flow test 1 verifies:

- turning on/off whole device
- paring functionality
- putting device into stand-by regime

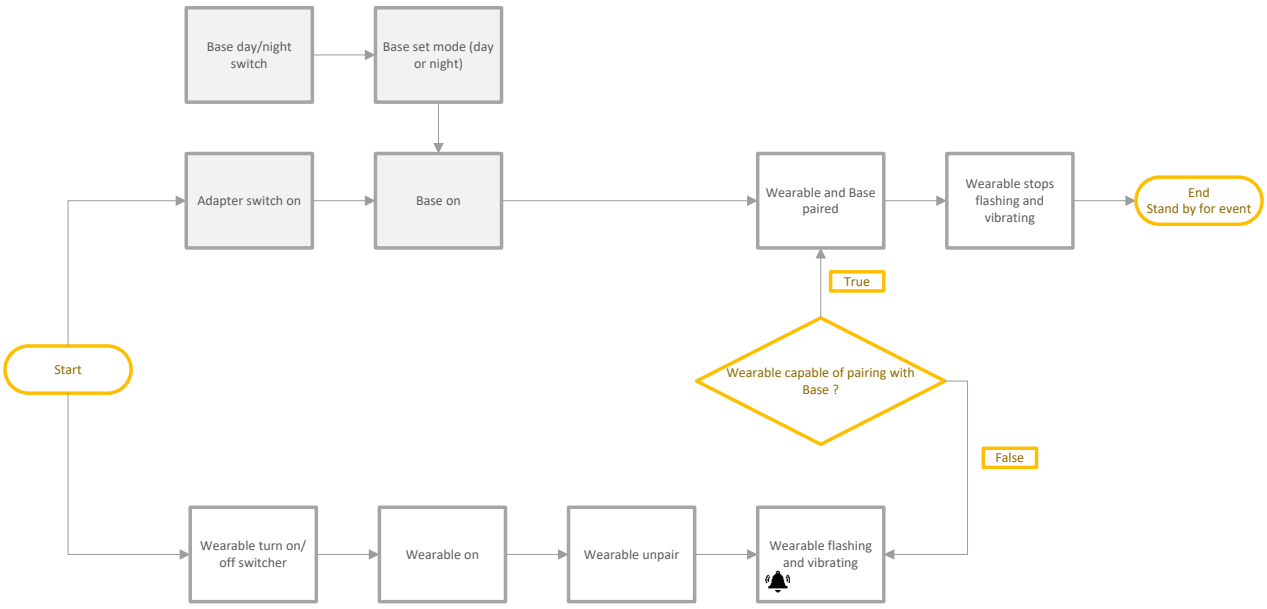



**Figure 56: AP-NURSE Home event flow 1**

**Event flow test 2**

Event flow test 2 verifies:

- unpairing due to loss of signal
    - base turned off
    - base reset
    - wearable turn off
- unpairing due to increase of the distance between the receiver and the transmitter

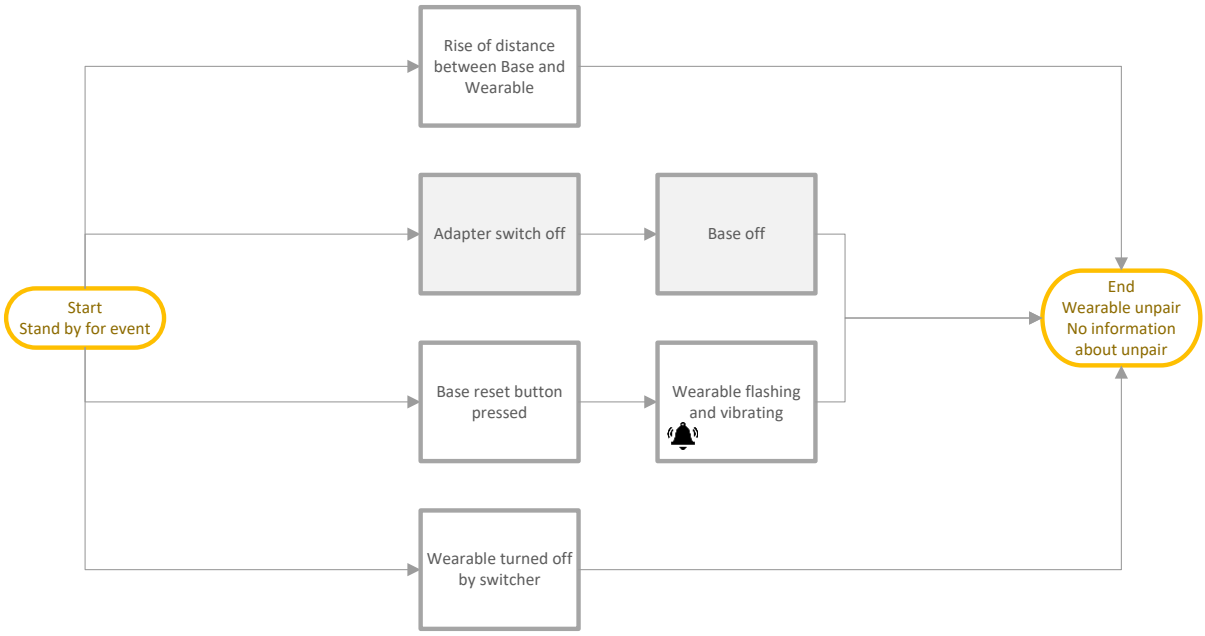



**Figure 57: AP-NURSE Home event flow 2**

**Event flow test 3**

Event flow test 3 verifies:

- the functionality of the AP-NURSE Home wearebles of displaying the battery level

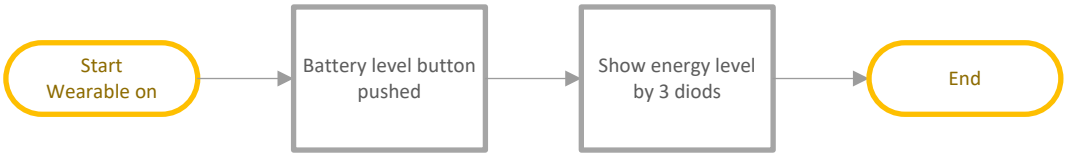



**Figure 58: AP-NURSE Home event flow 3**

**Event flow test 4**

Event flow test 4 verifies:

- filtering abnormal and critical conditions
- day/night event filtering
- abnormal condition/ critical condition alarm trigger

- alarm signalization / alarm muting
- time delay from muting the alert to stand by mode (device in not perceptible to ambient conditions)

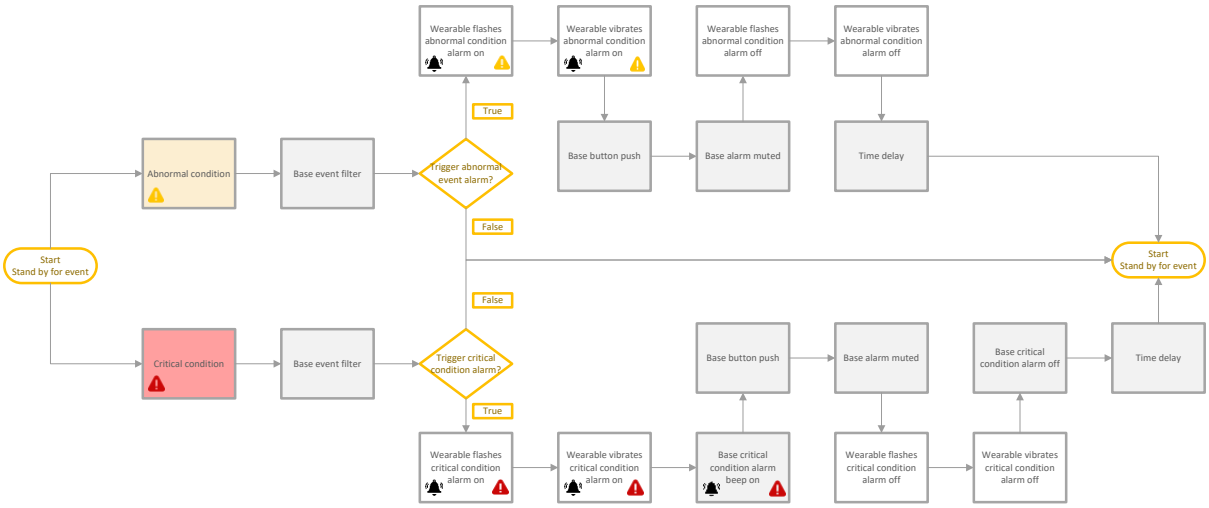



**Figure 59: AP-NURSE Home event flow 4**

**Specialized tests and sensor tests - ST-H**

Specialized tests that cannot be categorized in any of above categories:

- Unpairing distance in case of clear distance between the wearable and the base.
- Unpairing distance in case of distance with barriers between the wearable and the base.
- Testing of PIR movement sensor with collimator. Collimator provides tighter angle in which movement sensor triggers alarm. This can be applied as a barrier crossing the detection area.
- Functionality of each sensor, triggering an abnormal condition and a critical condition.

Taking into account all event flow tests, specialized test and sensor tests, 24 function tests were defined for the AP-NURSE Home devices covering test for all AP-NURSE Home versions. The final overview and the description of function tests of for AP-NURSE Home devices can be found in **Table 6**.

## Table 6: Overview and description of AP-NURSE Home function tests

| Test | Inicial state | Events | | | | | End state |
|---|---|---|---|---|---|---|---|
| EFT-H-1 | Wearable off - Base off | Base adapter switch on | Wearable on | Wearable pair | Signalize pairing | | Stand-by |
| EFT-H-2 | Stand-by | Base dapter off No baterry in Base | Wearable unpair | Base on | Wearable pairing | Signalize pairing | Stand-by |
| EFT-H-3 | Stand-by | Base reset | Wearable unpair | Wearable pair | Signalize pairing | | Stand-by |
| EFT-H-4 | Stand-by | Wearable off | Wearable on | Wearable pair | Signalize pairing | | Stand-by |
| EFT-H-5 | Stand-by | rise in distance between reciever and transmitter | Wearable unpair | Fall in distance between reciever and transmitter | Wearable pairing | | Stand-by |
| EFT-H-6 | Stand-by | Base adapter off | Base powered from baterry, nothing happends | Base adapter on | Wearable wibrates | | Stand-by |
| EFT-H-7 | Wearable on | Click baterry button | | | | | Show baterry level |
| EFT-H-8 | Wearable on | Click baterry button | Verify LED signalization of the current baterry level by voltage measurement for diferent states | | | | Show baterry level |
| EFT-H-9 | Stand-by | Trigger abnormal condition | Filtering event | | | | Stand-by |
| EFT-H-10 | Stand-by | Trigger critical condition | Not filtering event | Signalize critical condtition alarm | Mute critical condition alarm | | Stand-by |
| EFT-H-11 | Stand-by | Trigger abnormal condition | Not filtering event | Signalize abnormal condition alarm | Mute abnormal condition alarm | | Stand-by |
| EFT-H-12 | Stand-by | Trigger abnormal condition | Not filtering event | Signalize abnormal condition alarm | Mute abnormal condition alarm | Time delay | Find out the best practical time delay |
| ST-H-1 | Stand-by | Trigger temperature sensor on Base | | | | | Catch abnormal condition |
| ST-H-2 | Stand-by | Trigger humidity sensor on Base | | | | | Catch abnormal condition |
| ST-H-3 | Stand-by | Trigger movement sensor on Base | | | | | Catch abnormal condition |
| ST-H-4 | Stand-by | Trigger accelerometer sensor on Base | | | | | Catch abnormal condition |
| ST-H-5 | Stand-by | Trigger noise sensor on Base | | | | | Catch abnormal condition |
| ST-H-6 | Stand-by | Trigger light sensor on Base | | | | | Catch abnormal condition |
| ST-H-7 | Stand-by | Trigger gas MQ135 sensor on Base | | | | | Catch critical condition |
| ST-H-8 | Stand-by | Trigger gas MQ5 sensor on Base | | | | | Catch critical condition |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ST-H-9 | Wearable off - Base off | 20m distance between reciever and transmitter, no barriers | Base adapter switch on | Wearable on | Lower the distance between reciever and transmitter | Wearable pairing | Find out the maximum distance for the wearable to pair with the base in case of no bariers between them |
| ST-H-10 | Wearable off - Base off | 20m distance between reciever and transmitter, with barriers | Base adapter switch on | Wearable on | Lower the distance between reciever and transmitter | Wearable pairing | Find out maximum distance for the wearabôe to pair with the Base in case of single or several walls between them |
| ST-H-11 | Stand-by | Movement sensro volimator mounted on Base | Trigger movement sensor on Base with different distance and angle of triggering object | | | | Evaluate usage of movement sensor with collimator for barier detection |
| ST-H-12 | Stand-by | Fall of the Base | Trigger giroscope event | | | | Evaluate the posibility to recognize movement of the base |

#### 4.2.1.2. AP-NURSE Care

##### 4.2.1.2.1. M5Stack

Several functional test were designed to be performed on every AP-NURSE Care M5stack device. The aim of the listed tests is to verify the basic functionality and the performance of the developed device. These tests are based on the events presented in schemes in **Figure 60 - Figure 63**. There are five basis event flow tests from which function test are derived. All function test are performed at least 10 times and the results are evaluated in test protocols. In the event flow charts the following marking are used:

- Grai infill box – functionality of the base
- White infill box – functionality of the IS system

In the following section, the five AP-NURSE Care M5Stack event flow tests are briefly explained.

**Event flow test 1**

Event flow test 1 verifies:

- turning on/off the base


**Figure 60: AP-NURSE Care event flow 1**

**Event flow test 3**

Event flow test 3 verifies:

- unpairing the base due to the lack of WiFi signal
- turning off and on the base with connection to information system
- failure of the information system
- resetting base

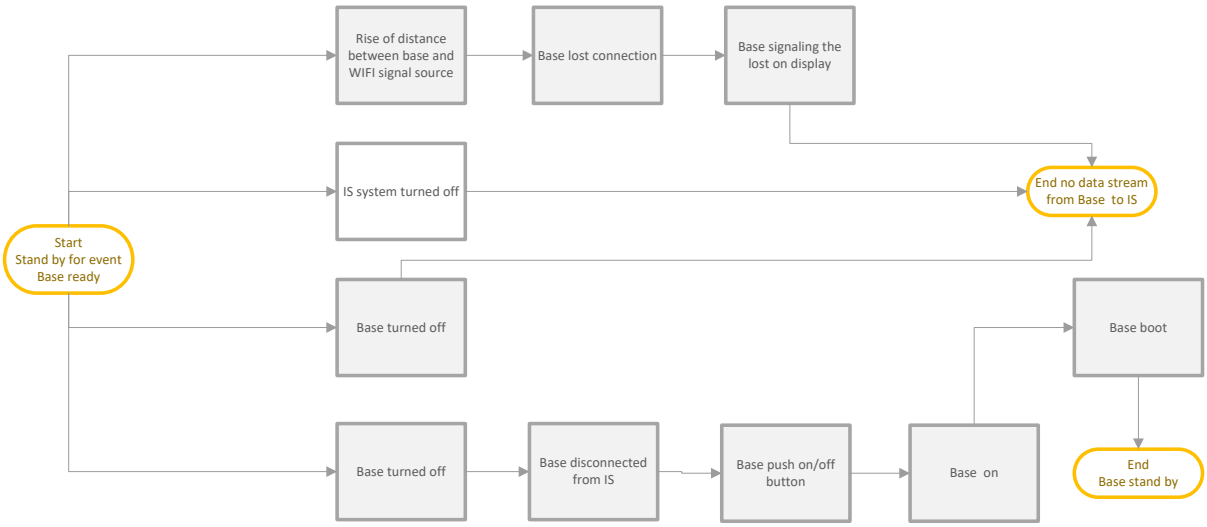



**Figure 61: AP-NURSE Care event flow 3**

### Event flow test 4

Event flow test 4 verifies:

- manual setup of a wi-fi access point


**Figure 62: AP-NURSE Care event flow 4**

### Event flow test 5

Event flow test 5 verifies:

- filtering abnormal and critical conditions
- day/night event filtering
- abnormal / critical condition alarm trigger
- alarm signalization / alarm muting

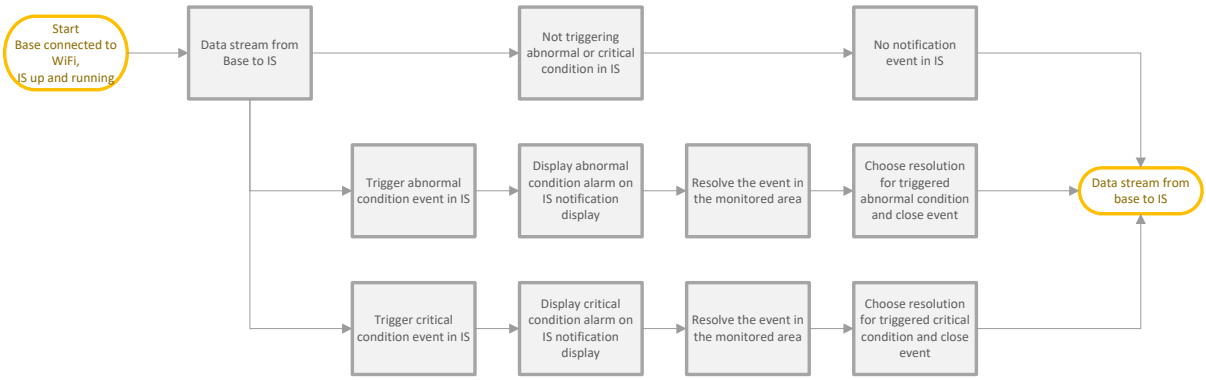



**Figure 63: AP-NURSE Care event flow 5**

### Specialized tests and sensor tests - ST

Special tests that cannot be categorized in any of above categories:

- functionality of each sensor, triggering an abnormal condition and critical condition

Taking into account all event flow and sensor tests, 15 function test were defined for AP-NURSE Care M5stack devices. The final overview and description of function tests of for AP-NURSE Care – M5Stack devices can be found in **Table 7**.

## Table 7: Overview and description of AP-NURSE Care M5Stack function tests

| Test | Initial state | Event | | | | | End state |
|---|---|---|---|---|---|---|---|
| EFT-M-1 | Base off, WiFi network available, IS system up and running | Base push on/off button | Base on | Base boot | Base signalizing the connection to WiFi network | Base gathering data from installed sensors | Data stream from Base to IS |
| EFT-M-4 | Base connected to WiFi network, IS up and running | rise of distance between the Base and WiFi signal source | Base lost connection | Base signalizing the lost connection on display | Base disconnected from IS | | Data stream from Base to IS |
| EFT-M-5 | Base connected to WiFi network, IS up and running | IS system turned off | Base disconnected from IS | | | | Data stream from Base to IS |
| EFT-M-6 | Base connected to WiFi network, IS up and running | Base turned off | Base disconnected from IS | | | | No data stream from Base to IS |
| EFT-M-7 | Base connected to WiFi network, IS up and running | Base turned off | Base disconnected from IS | EFT-M-1 | | | Data stream from Base to IS |
| EFT-M-8 | Base turned on, not connected to WiFi network | Base creates access point to WiFi network with local server | Connection to access point with any device on address 192.168.4.1 | Insert name and password into log in form in browser | Show connection logs in browser | EFT-M-7 | Data stream from Base to IS |
| EFT-M-9 | Base connected to WiFi, IS up and running | data stream from Base to IS | Not triggering abnormal or critical condition in IS | No notification event in IS | No notification display in IS | | Stand-by for Base connected to WiFi, IS up and running |
| EFT-M-10 | Base connected to WiFi, IS up and running | data stream from Base to IS | Triggering abnormal condition in IS | Display abnormal condition alarm on IS notification display | Resolve the event in the monitored area | Choose resolution for triggered abnormal condition and close event | Stand-by for Base connected to WiFi, IS up and running |
| EFT-M-11 | Base connected to WiFi, IS up and running | data stream from Base to IS | Triggering critical condition in IS | Display critical condition alarm on IS notification display | Resolve the event in the monitored area | Choose resolution for triggered critical condition and close event | Stand-by for Base connected to WiFi, IS up and running |
| ST-M-1 | Base connected to WiFi, IS up and running | Trigger temperature sensor on Base | | | | | Measured data visualized in IS |
| ST-M-2 | Base connected to WiFi, IS up and running | Trigger humidity sensor on Base | | | | | Measured data visualized in IS |
| ST-M-3 | Baset connected to WiFi, IS up and running | Trigger movement sensor on Base | | | | | Measured data visualized in IS |
| ST-M-6 | Base connected to WiFi, IS up and running | Trigger light sensor on Base | | | | | Measured data visualized in IS |
| ST-M-7 | Base connected to WiFi, IS up and running | Trigger gas sensor on Base | | | | | Measured data visualized in IS |
| ST-M-8 | Base connected to WiFi, IS up and running | Trigger IR sensor on Base | | | | | Measured data visualized in IS |

#### 4.2.1.2.2. Waspmote

Due to the delay in the development of AP-NURSE Care Waspmote devices, no final prototypes have been prepared for testig, thus the testing procuder cannot be defined at this moment. After finalizing the first prototypes, unique event flow tests will be defined for these devices, which will in general follow the logic used fot the M5Stack devices, but will also include cases specific for the Waspmote platform. These function tests will be defined in the updated version of this deliverable.

### 4.2.2. Test cases

To simulate the behaviour of AP-NURSE devices a series of test cases were created. These test cases serve as a tool to find out specific threshold values for sensors and to test the overall practical use of the AP-NURSE devices. The selection of tests cases was driven by three criteria:

- Location in which the AP-NURSE devices are to be deployed
- Type of the patient (mobile/immobile)
- Monitoring regime (day/night)

According to specific applications, individual alerts can be muted. For example: walking in the room during the daylight. However, in general, the system must detect all events and the device should decided, based on the implemented logic, whether to trigger an alert or not.

In future testing and implementation of these devices on site, it will be very important to set the threshold according to the specific placement of the device. All bases must feature flexible addition and removal of sensors due to various reasons.

#### 4.2.2.1. AP-NURSE Home

Each AP-NURSE Home version has its own set of test cases, which were designed to be tested in the physical testing environment. The internal logic of the base was adjusted for each version as well. The final list of these cases for each sensor and their expected behaviour during specific event and resulted alert after the event is summarized in **Table 8.** As it can be seen, the table contains the noise sensor, which is no longer included in the AP-NURSE versions, but only to highlight the fact, that it has no impact on the test cases. There is also a humidity sensor mentioned, which is included in the BME280 sensor, but it also does not produce any alert at this moment. It is listed only for future purposes.

## Table 8 Test case list for each AP-NURSE Home device version

| Test case | Version | Mode of device | initial state | event | Sensor detects the change in the environment | | | | | | | | Alert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Motion | Force | Noise | Light | Gas | Temp. | Humidity | Time | |
| 1 | AP1-H | day | patient lying in the bed | patient got up from the bed | ✓ | | | | | | | | ✗ |
| 2 | | night | patient lying in the bed | patient got up from the bed | ✓ | | | | | | | | ! |
| 3 | | day | patient in the bedroom | smoking | | | | | ✓ | | | | ! |
| 4 | | night | patient in the bedroom | smoking | | | | | ✓ | | | | ! |
| 5 | | night | patient in the bed | patient leave bed | | ✓ | | | | | | | ! |
| 6 | | day | patient in the room | patient walking in the room | ✓ | | | | | | | | ✗ |
| 7 | | night | patient in the room | TV on | | | | ✓ | | | | | ! |
| 8 | | night | patient in the room | lamp on | | | | ✓ | | | | | ! |
| 9 | | day | patient in the room | open window temperature drop | | | | | | ✓ | | | ! |
| 10 | | night | patient in the room | open window temperature drop | | | | | | ✓ | | | ! |
| 11 | | day | patient in the room | boiling water | | | | | | | ✓ | | ✗ |
| 12 | AP7-H | day | patient lying in the bed | patient got up from the bed | ✓ | | | | | | | | ✗ |
| 13 | | night | patient lying in the bed | patient got up from the bed | ✓ | | | | | | | | ! |
| 14 | | day | patient in the bedroom | smoking | | | | | ✓ | | | | ! |
| 15 | | night | patient in the bedroom | smoking | | | | | ✓ | | | | ! |
| 16 | | day | patient in the room | patient walking in the room | ✓ | | | | | | | | ✗ |
| 17 | | night | patient in the room | TV on | | | | ✓ | | | | | ! |
| 18 | | night | patient in the room | lamp on | | | | ✓ | | | | | ! |
| 19 | | day | patient in the room | open window temperature drop | | | | | | ✓ | | | ! |
| 20 | | night | patient in the room | open window temperature drop | | | | | | ✓ | | | ! |
| 21 | | day | patient in the room | boiling water | | | | | | | ✓ | | ✗ |
| 22 | AP2-H | day | patient in the room | enter the bathroom | ✓ | | | | | | | | ! |
| 23 | | night | patient in the room | enter the bathroom | ✓ | | | | | | | | ! |
| 24 | | day | in the bathroom | stuck in the bathroom | | | | | | | | ✓ | ! |
| 25 | | night | in the bathroom | stuck in the bathroom | | | | | | | | ✓ | ! |
| 26 | | day | in the bathroom | leave the bathroom | ✓ | | | | | | | | ✗ |
| 27 | | night | in the bathroom | leave the bathroom | ✓ | | | | | | | | ✗ |
| 28 | AP4-H | day | empty hallway | no movement in it | | | | | | | | | ✗ |
| 29 | | day | empty hallway | movement | | | | | | | | | ✗ |
| 30 | | night | empty hallway | no movement in it | | | | | | | | | ✗ |
| 31 | | night | empty hallway | movement | ✓ | | | | | | | | ! |
| 32 | AP6-H | day | leaking gas | | | | | | ✓ | | | | ! |
| 33 | | night | leaking gas | | | | | | ✓ | | | | ! |
| 34 | | night | empty kitchen | movement in the kitchen | ✓ | | | | | | | | ! |
| 35 | | day | empty kitchen | light in the kitchen | | | | ✓ | | | | | ! |

#### 4.2.2.2. AP-NURSE Care

##### 4.2.2.2.1. M5Stack

**Table 9** reflects the requirements for the final versions of AP-NURSE Care. Based on this procedure, the functionality and behaviour of the used sensor was tested together with the overall functionality of all AP-NURSE versions.

**Table 9: Test case list for each AP-NURSE Care M5stack device**

| Test case | Version | Mode of device | initial state | event | Sensor detects the change in the environment | | | | | | | | Alert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Motion | Force | Noise | Light | Gas | Temp. | Humidity | Time | |
| 1 | AP1-M | day | patient lying in the bed | patient got up from the bed | ✓ | | | | | | | | ✗ |
| 2 | | night | patient lying in the bed | patient got up from the bed | ✓ | | | | | | | | ! |
| 3 | | day | patient in the bedroom | smoking | | | | | ✓ | | | | ! |
| 4 | | night | patient in the bedroom | smoking | | | | | ✓ | | | | ! |
| 5 | | night | patient in the bed | patient leave bed | | ✓ | | | | | | | ! |
| 6 | | day | patient in the room | patient walking in the room | ✓ | | | | | | | | ✗ |
| 7 | | day | patient in the room | open window temperature drop | | | | | | ✓ | | | ! |
| 8 | | night | patient in the room | open window temperature drop | | | | | | ✓ | | | ! |
| 9 | | day | patient in the room | boiling water | | | | | | | ✓ | | ✗ |
| 10 | AP2-M | day | patient in the room | enter the bathroom | ✓ | | | | | | | | ⚠ |
| 11 | | night | patient in the room | enter the bathroom | ✓ | | | | | | | | ⚠ |
| 12 | | day | in the bathroom | stuck in the bathroom | | | | | | | | ✓ | ! |
| 13 | | night | in the bathroom | stuck in the bathroom | | | | | | | | ✓ | ! |
| 14 | | day | in the bathroom | leave the bathroom | ✓ | | | | | | | | ✗ |
| 15 | | night | in the bathroom | leave the bathroom | ✓ | | | | | | | | ✗ |
| 16 | AP4-M | day | empty hallway | no movement in it | | | | | | | | | ✗ |
| 17 | | day | empty hallway | movement | | | | | | | | | ✗ |
| 18 | | night | empty hallway | no movement in it | | | | | | | | | ✗ |
| 19 | | night | empty hallway | movement | ✓ | | | | | | | | ! |
| 20 | AP6-M | day | leaking gas | | | | | | ✓ | | | | ! |
| 21 | | night | leaking gas | | | | | | ✓ | | | | ! |
| 22 | | night | empty kitchen | movement in the kitchen | ✓ | | | | | | | | ! |
| 23 | | day | empty kitchen | light in the kitchen | | | | ✓ | | | | | ⚠ |

Explanatory notes on alert:

- permitted event, no alert ✗
- abnormal condition ⚠
- critical condition !

#### 4.2.2.2.2. Waspmote

Due to the delay in the development of AP-NURSE Care Waspmote devices, no final prototypes have been prepared for testig, thus the testing procuder cannot be defined at this moment. After finalizing the first prototypes, unique test cases will be defined for these devices, which will in general follow the logic used fot the M5Stack devices, but will also include cases specific for the Waspmote platform. These test cases will be defined in the updated version of this deliverable.

## 4.3. Testing results

### 4.3.1. Function tests

#### 4.3.1.1. AP-NURSE Home

The function tests were carried out in two ways, both giving the same results:

- Testing of the selected AP-NURSE Home version with only the tested sensor connected
- Testing of the selected AP-NURSE Home version with all sensor connected

This testing procedure verifies, if there are any conflicts in the communication pathways, when multiple sensors are used, even though everything is connected and assembled correctly.

The Following **Table 10 - Table 13** are the test protocols that were carried out as a result of all function tests for all proposed versions of the AP-NURSE Home devices. The testing protocol of the AP7-H is omitted, since this version uses the same configuration of sensors as AP1-H, however is placed in a different location.

**Table 10: Function test protocol for AP-NURSE Home - AP1-H**

| Device: | AP1-H | Date: | 3.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| Name | Result | Notes | |
| EFT-H-1 | ☑ | | |
| EFT-H-2 | ☑ | | |
| EFT-H-3 | ☑ | In some cases Reset is so quick that the wearable remains paired | |
| EFT-H-4 | ☑ | | |
| EFT-H-5 | ☑ | | |
| EFT-H-6 | ☑ | In some cases event adapter on triggers PIR sensor | |
| EFT-H-7 | ☑ | | |
| EFT-H-8 | ☑ | Functional for two out of three led indicators | |
| EFT-H-9 | ☑ | | |
| EFT-H-10 | ☑ | | |
| EFT-H-11 | ☑ | | |
| EFT-H-12 | ☑ | | |
| ST-H-1 | ~ | Not included in this AP version | |

| Device: | AP1-H | Date: | 3.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| ST-H-2 | ~ | Not included in this AP version | |
| ST-H-3 | ☑ | | |
| ST-H-4 | ☑ | Not installed in device – pressure instead | |
| ST-H-5 | ~ | Not included in this AP version | |
| ST-H-6 | ☑ | See light sensor sensibility test | |
| ST-H-7 | ☑ | | |
| ST-H-8 | ☑ | | |
| ST-H-9 | ☑ | 18.85 m | |
| ST-H-10 | ☑ | 10 m – 3 x 0.2 m thick wall between devices | |
| ST-H-11 | ☑ | | |
| ST-H-12 | ~ | Not included in this AP version | |
| explanatory note | | ☒ - unexpected result | ☑ - expected result |

**Note:**

Th AP1-H version is primary designed to be used under the patient's bed. All proposed sensors are functional and are able to receive changes in the environment.

**Table 11: Function test protocol for AP-NURSE HOME - AP2-H**

| Device: | AP2-H | Date: | 3.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| Name | Result | Notes | |
| EFT-H-1 | ☑ | | |
| EFT-H-2 | ☑ | | |
| EFT-H-3 | ☑ | In some cases, Reset is so quick that the wearable remains paired | |
| EFT-H-4 | ☑ | | |
| EFT-H-5 | ☑ | | |
| EFT-H-6 | ☑ | In some cases, event adapter on triggers PIR sensor | |
| EFT-H-7 | ☑ | | |
| EFT-H-8 | ☑ | Functional for two out of three led indicators | |
| EFT-H-9 | ☑ | | |
| EFT-H-10 | ☑ | | |
| EFT-H-11 | ☑ | | |
| EFT-H-12 | ☑ | | |
| ST-H-1 | ~ | Not included in this AP version | |

| Device: | AP2-H | Date: | 3.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava Faculty of Electrical Engineering and Information Technology Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| ST-H-2 | ~ | Not included in this AP version | |
| ST-H-3 | ☑ | | |
| ST-H-4 | ~ | Not included in this AP version | |
| ST-H-5 | ☒ | Very low sensitivity unable to use | |
| ST-H-6 | ~ | Not included in this AP version | |
| ST-H-7 | ☑ | | |
| ST-H-8 | ☑ | | |
| ST-H-9 | ☑ | 18.85 m | |
| ST-H-10 | ☑ | 10 m – 3 x 0.2 m thick wall between devices | |
| ST-H-11 | ☑ | | |
| ST-H-12 | ~ | Not included in this AP version | |
| explanatory note | | ☒ - unexpected result | ☑ - expected result |

**Note:**

The AP2-H version is primary designed to be used to monitor the bathroom door movement, or generally the around bathroom. Most of the proposed sensors are functional and are able to receive changes in the environment.

**Table 12: Function test protocol for AP-NURSE HOME – AP4-H**

| Device: | AP4-H | Date: | 3.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava Faculty of Electrical Engineering and Information Technology Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| Name | Result | Notes | |
| EFT-H-1 | ☑ | | |
| EFT-H-2 | ☑ | | |
| EFT-H-3 | ☑ | In some cases Reset is so quick that wearable remains paired | |
| EFT-H-4 | ☑ | | |
| EFT-H-5 | ☑ | | |
| EFT-H-6 | ☑ | In some cases event adapter on triggers PIR sensor | |
| EFT-H-7 | ☑ | | |
| EFT-H-8 | ☑ | Functional for two out of three led indicators | |
| EFT-H-9 | ☑ | | |
| EFT-H-10 | ☑ | | |
| EFT-H-11 | ☑ | | |
| EFT-H-12 | ☑ | | |

| Device: | AP4-H | Date: | 3.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava Faculty of Electrical Engineering and Information Technology Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| ST-H-1 | ~ | Not included in this AP version | |
| ST-H-2 | ~ | Not included in this AP version | |
| ST-H-3 | ☑ | | |
| ST-H-4 | ~ | Not included in this AP version | |
| ST-H-5 | ☒ | Very low sensitivity, unable to use | |
| ST-H-6 | ~ | Not included in this AP version | |
| ST-H-7 | ~ | Not included in this AP version | |
| ST-H-8 | ~ | Not included in this AP version | |
| ST-H-9 | ☑ | 18.85 m | |
| ST-H-10 | ☑ | 10 m - 3 x 0.2 m thick wall between devices | |
| ST-H-11 | ☑ | | |
| ST-H-12 | ~ | Not included in this AP version | |
| explanatory note | | ☒ - unexpected result | ☑ - expected result |

**Note:**

The AP4-H version is primary designed to be used in common rooms, stairs and forbidden zones for patients. Most of the proposed sensors are functional and are able to receive changes in the environment.

**Table 13: Function test protocol for AP-NURSE HOME - AP6-H**

| Device: | AP6-H | Date: | 3.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava Faculty of Electrical Engineering and Information Technology Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| Name | Result | Notes | |
| EFT-H-1 | ☑ | | |
| EFT-H-2 | ☑ | | |
| EFT-H-3 | ☑ | In some cases Reset is so quick that wearable remains paired | |
| EFT-H-4 | ☑ | | |
| EFT-H-5 | ☑ | | |
| EFT-H-6 | ☑ | In some cases event adapter on triggers PIR sensor | |
| EFT-H-7 | ☑ | | |
| EFT-H-8 | ☑ | Functional for two out of three led indicators | |
| EFT-H-9 | ☑ | | |
| EFT-H-10 | ☑ | | |
| EFT-H-11 | ☑ | | |
| EFT-H-12 | ☑ | | |

| Device: | AP6-H | Date: | 3.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava Faculty of Electrical Engineering and Information Technology Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| ST-H-1 | ~ | Not included in this AP version | |
| ST-H-2 | ~ | Not included in this AP version | |
| ST-H-3 | ☑ | | |
| ST-H-4 | ~ | Not included in this AP version | |
| ST-H-5 | ☒ | Very low sensitivity unable to use | |
| ST-H-6 | ☑ | See light sensor sensibility test | |
| ST-H-7 | ☑ | | |
| ST-H-8 | ☑ | | |
| ST-H-9 | ☑ | 18.85 m | |
| ST-H-10 | ☑ | 10 m - 3 x 0.2 m thick wall between devices | |
| ST-H-11 | ☑ | | |
| ST-H-12 | ~ | Not included in this AP version | |
| explanatory note | ☒ - unexpected result | ☑ - expected result | |

**Note:**

The AP6-H version is primary designed to monitor the kitchen area. Most of the proposed sensors are functional and are able to receive changes in the environment.

#### 4.3.1.1.1. Conclusion

All sensors except the noise sensor were able to produce the desired output values resulting from the changes in the parameters of the monitored environment. The noise sensor was also able to produce output values and as well as the settings of the sensibility of the sensor seemed to be working, however communication issues with the ESP8266 microcontroller were encountered. Therefore, the noise sensor is not included in the AP-NURSE Home versions. However in the future, if noise sensor is required, a different type of noise sensor could be used.

### 4.3.1.2. AP-NURSE Care

#### 4.3.1.2.1. M5Stack

The function tests were carried out in two ways, both giving the same results:

- Testing of the selected AP-NURSE Care - M5Stack version with only the tested sensor connected
- Testing of the selected AP-NURSE Care - M5Stack version with all sensor connected

This testing procedure verifies, if there are any conflicts in the communication pathways, when multiple sensors are used, even though everything is connected and assembled correctly.

The Following **Table 10** - **Table 13** are the test protocols that were carried out as a result of all function tests for all proposed versions of the AP-NURSE Care - M5Stack device.

Table 14: Function test protocol for AP-NURSE Care - M5Stack - AP1-M

| Device: | AP1-M | Date: | 20.1.2021 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| Name | Result | Notes | |
| EFT-M-1 | ☑ | Works correctly | |
| EFT-M-2 | ~ | Not included in this AP version | |
| EFT-M-3 | ~ | Not included in this AP version | |
| EFT-M-4 | ☑ | | |
| EFT-M-5 | ☑ | | |
| EFT-M-6 | ☑ | | |
| EFT-M-7 | ☑ | | |
| EFT-M-8 | ☑ | | |
| EFT-M-9 | ~ | Not included in this AP version | |
| EFT-M-10 | ~ | Not included in this AP version | |
| EFT-M-11 | ~ | Not included in this AP version | |
| ST-M-1 | ☑ | | |
| ST-M-2 | ☑ | | |
| ST-M-3 | ☑ | Works only in range of PIR sensor | |
| ST-M-4 | ~ | Not included in this AP version | |
| ST-M-5 | ~ | Not included in this AP version | |
| ST-M-6 | ~ | Not included in this AP version | |
| ST-M-7 | ☑ | | |
| ST-M-8 | ~ | Not included in this AP version | |
| ST-M-9 | ☑ | Dependents on WiFi strength | |
| ST-M-10 | ☑ | Dependents on WiFi strength | |
| explanatory note | ☒ - unexpected result | ☑ - expected result | |

**Note:**

Th AP1-M version is primary designed to be used under the patient's bed. All proposed sensors are functional and are able to receive changes in the environment.

Table 15: Function test protocol for AP-NURSE Care - M5Stack- AP2 - M

| Device: | AP2-M | Date: | 21.1.2021 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| Name | Result | Notes | |
| EFT-M-1 | ☑ | Works correctly | |
| EFT-M-2 | ~ | Not included in this AP version | |
| EFT-M-3 | ~ | Not included in this AP version | |
| EFT-M-4 | ☑ | | |
| EFT-M-5 | ☑ | | |
| EFT-M-6 | ☑ | | |
| EFT-M-7 | ☑ | | |
| EFT-M-8 | ☑ | | |
| EFT-M-9 | ~ | Not included in this AP version | |
| EFT-M-10 | ~ | Not included in this AP version | |
| EFT-M-11 | ~ | Not included in this AP version | |
| ST-M-1 | ~ | Not included in this AP version | |
| ST-M-2 | ~ | Not included in this AP version | |
| ST-M-3 | ☑ | Works only in range of ToF sensor | |
| ST-M-4 | ~ | Not included in this AP version | |
| ST-M-5 | ~ | Not included in this AP version | |
| ST-M-6 | ~ | Not included in this AP version | |
| ST-M-7 | ~ | Not included in this AP version | |
| ST-M-8 | ~ | Not included in this AP version | |
| ST-M-9 | ☑ | Dependents on WiFi strength | |
| ST-M-10 | ☑ | Dependents on WiFi strength | |
| explanatory note | | ☒ - unexpected result | ☑ - expected result |

**Note:**

The AP2-M version is primary designed to be used to monitor the bathroom door movement, or generally the around bathroom. Most of the proposed sensors are functional and are able to receive changes in the environment.

Table 16: Function test protocol for AP-NURSE Care - M5Stack - AP4 - M

| Device: | AP4-M | Date: | 20.1.2021 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| Name | Result | Notes | |
| EFT-M-1 | ☑ | Works correctly | |
| EFT-M-2 | ~ | Not included in this AP version | |
| EFT-M-3 | ~ | Not included in this AP version | |
| EFT-M-4 | ☑ | | |
| EFT-M-5 | ☑ | | |
| EFT-M-6 | ☑ | | |
| EFT-M-7 | ☑ | | |
| EFT-M-8 | ☑ | | |
| EFT-M-9 | ~ | Not included in this AP version | |
| EFT-M-10 | ~ | Not included in this AP version | |
| EFT-M-11 | ~ | Not included in this AP version | |
| ST-M-1 | ~ | Not included in this AP version | |
| ST-M-2 | ~ | Not included in this AP version | |
| ST-M-3 | ☑ | Works only in range of PIR sensor | |
| ST-M-4 | ~ | Not included in this AP version | |
| ST-M-5 | ~ | Not included in this AP version | |
| ST-M-6 | ~ | Not included in this AP version | |
| ST-M-7 | ~ | Not included in this AP version | |
| ST-M-8 | ~ | Not included in this AP version | |
| ST-M-9 | ☑ | Dependent on WiFi strength | |
| ST-M-10 | ☑ | Dependent on WiFi strength | |
| explanatory note | ☒ - unexpected result | ☑ - expected result | |

**Note:**

The AP4-M version is primary designed to be used in common rooms, stairs and forbidden zones for patients. Most of the proposed sensors are functional and are able to receive changes in the environment.

Table 17: Function test protocol for AP-NURSE Care - M5Stack - AP6 - M

| Device: | AP6-M | Date: | 20.1.2021 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Power and Applied Electrical Engineering | Name: | Jozef Bendík |
| TESTS | | | |
| Name | Result | Notes | |
| EFT-M-1 | ☑ | Works correctly | |
| EFT-M-2 | ~ | Not included in this AP version | |
| EFT-M-3 | ~ | Not included in this AP version | |
| EFT-M-4 | ☑ | | |
| EFT-M-5 | ☑ | | |
| EFT-M-6 | ☑ | | |
| EFT-M-7 | ☑ | | |
| EFT-M-8 | ☑ | | |
| EFT-M-9 | ~ | Not included in this AP version | |
| EFT-M-10 | ~ | Not included in this AP version | |
| EFT-M-11 | ~ | Not included in this AP version | |
| ST-M-1 | ☑ | | |
| ST-M-2 | ☑ | | |
| ST-M-3 | ☑ | Works only in range of PIR sensor | |
| ST-M-4 | ~ | Not included in this AP version | |
| ST-M-5 | ~ | Not included in this AP version | |
| ST-M-6 | ☑ | | |
| ST-M-7 | ☑ | | |
| ST-M-8 | ~ | Not included in this AP version | |
| ST-M-9 | ☑ | Dependent on WiFi strength | |
| ST-M-10 | ☑ | Dependent on WiFi strength | |
| explanatory note | ☒ - unexpected result | ☑ - expected result | |

**Note:**

The AP6-M version is primary designed to monitor the kitchen area. Most of the proposed sensors are functional and are able to receive changes in the environment.

All sensors to produce the desired output values resulting from the changes in the parameters of the monitored environment.

#### 4.3.1.2.2. Waspmote

Due to the delay in the oprogress of the AP-NURSE Care Waspmote, the function tests have not been performed so far. They will be performed in the forthcoming months and the results will be included in the updated version of this report.

## 4.3.2. Test Cases

### 4.3.2.1. AP-NURSE Home

The test cases were carried out in accordance with Table 8. The protocols shown in

**Table 18** - **Table 21** represent the results obtained in the testing environment, which is described in the previous section. The testing procedure is illustrated in Figure 64 and Figure 65.

**Figure 64: Testing of AP1-H, test case 1**

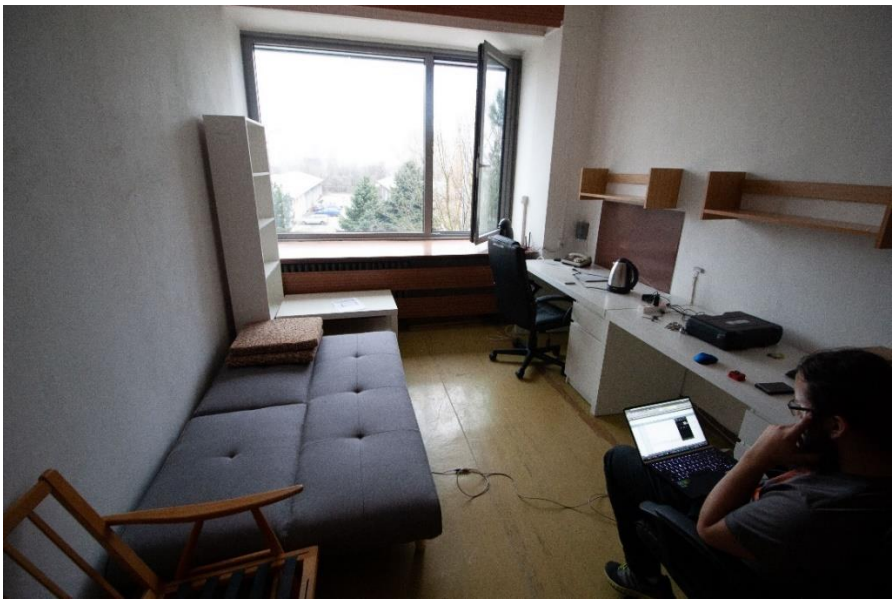


**Figure 65: Testing of AP1-H, test case 9**

Table 18: Test cases protocol for AP-NURSE Home AP1-H version

| Device: | AP1-H | Date: | 10.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Nuclear and Physical Engineering | Name: | Matej Cenký |
| Test case | | | |
| Number | Result | Notes | |
| 1 | ☑ | Motion sensor is reacting to all movement as designed, the only possible issue is the placement under the bed, so the whole area could be monitored. There is an alternative to use two devices with PIR sensors under the bed. The sensrors should be set individually on site. | |
| 2 | ☑ | | |
| 3 | ☒ | Gas sensors are placed in great distance from the possible source of smoke. The output values of the sensors did not change during the test. This sensor might be insuficient, if the room is equipped with external smoke sensor. | |
| 4 | ☒ | | |
| 5 | ☑ | Force / pressure sensor is sensitive on misplacement. When placed properly (under the body), it works as expected. Default output values when the bed was empty were under 20, when under lying person around 50 – 100, depending how the person was specifically on the bed with respect to the sensor placement. To maximize the effect, multiple force sensors are suggested or at least longer sensor to cover larger area under patient. Needs to be set individually on site. | |
| 6 | ☑ | Motion sensor is reacting to all movement as designed when placed properly. Needs to be set individually on site. | |
| 7 | ☒ | Light sensor output values were at maximum room light (main lights on ceiling or sunlight from big window) around 30 and during night around 5. The light sensor cannot detect small deviations from illuminance in the room as TV or lamp. | |
| 8 | ☒ | | |
| 9 | ~ | The temperature drop is not visible in the moment when the window is opened, instead the temperature is dropping slowly in time. Observation data are that drop in winter is 1 °C in 2 minutes (measured on 8/12/2020). This time constant is not implemented yet, but it is doable in near future. | |
| 10 | ~ | | |
| 11 | ☒ | Boiling water from electric kettle has not changed the humidity sensor output values. | |
| explanatory note | | ☒ - Failed ~ - Limited ☑ - Passed | |

**Note:**

The AP1-H version of the AP-NURSE Home device proved to be the most efficient for movement detection with partial functionality of detecting the basic differences between night and day, and offer possibilities for the utilization of the temperature sensor.

**Table 19: Test cases protocol for AP-NURSE Home AP2-H**

| Device: | AP2-H | Date: | 10.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Nuclear and Physical Engineering | Name: | Matej Cenký |
| Test case | | | |
| Number | Result | Notes | |
| 22 | ☑ | The same result as in test case number 12 and 13. | |
| 23 | ☑ | | |
| 24 | ☒ | N/AThe internal logic for evaluating the time constants is not yet implemented, it will be tested in the near future. | |
| 25 | ☒ | | |
| 26 | ☒ | Can't be tested because of the missing previous step of time constant evaluation in internal logic of device. Will be tested in near future. | |
| 27 | ☒ | | |
| explanatory note | | ☒ - Failed ~ - Limited ☑ - Passed | |

**Note:**

The AP2-H version of AP-NURSE Home proved to be the most efficient for movement detection. Further functionality is not implemented yet and will be tested in the near future.

**Table 20: Test cases protocol for AP-NURSE Home AP4-H**

| Device: | AP4-H | Date: | 10.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Nuclear and Physical Engineering | Name: | Matej Cenký |
| Test case | | | |
| Number | Result | Notes | |
| 28 | ☑ | OK | |
| 29 | ☑ | OK | |
| 30 | ☑ | OK | |
| 31 | ☑ | Movement sensor working properly, it needs to be set individually on site. | |
| explanatory note | | ☒ - Failed ~ - Limited ☑ - Passed | |

**Note:**

The AP4-H version of AP-NURSE Home is working properly and is applicable for monitoring the hallway.

**Table 21: Test cases protocol for AP-NURSE Home AP6-H**

| Device: | AP6-H | Date: | 10.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Nuclear and Physical Engineering | Name: | Matej Cenký |
| Test case | | | |
| Number | Result | Notes | |
| 32 | ~ | In case of smoke detection, the same results were achieved as in the test cases number 14 and 15. The detection of leaking gas was simulated with gas alternatives, the same sources as for smoke sensor. The default output value was around 110, with visible smoke around 130, with isopropylalcohol scent around 150, all measured in close distance. The precision strongly depends on its placement. | |
| 33 | ~ | | |
| 34 | ☑ | The same result as in test case number 31. | |
| 35 | ☑ | The same result as in test case number 18. Minor adaptations may be needed directly on site. | |
| explanatory note | | ☒ - Failed ~ - Limited ☑ - Passed | |

**Note:**

The AP6-H version of AP-NURSE Home is working properly for light and movement monitoring. The possibility to detect gases strongly depends on the source of gases and the placement of the AP-NURSE device.

**Table 22: Test cases protocol for AP-NURSE Home AP7-H**

| Device: | AP7-H | Date: | 10.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Nuclear and Physical Engineering | Name: | Matej Cenký |
| Test case | | | |
| Number | Result | Notes | |
| 12 | ☑ | Motion sensor is reacting to all movement as designed, the only possible issue is the placement over the bed, so numerous false positive alerts could be produced when screening the patient when moving in bed in sleep (this scenario was simulated). Needs to be set individually on site. | |
| 13 | ☑ | | |
| 14 | ☑ | Smoke sensor output values: default = 10-15, visible smoke = 25, isopropylalcohol scent = 50. Highly dependent on device placement, values measured at close distance. | |
| 15 | ☑ | | |
| 16 | ☑ | The same result as in test case number 12 and 13. | |

| Device: | AP7-H | Date: | 10.12.2020 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Nuclear and Physical Engineering | Name: | Matej Cenký |
| Test case | | | |
| 17 | ☒ | Detection of turning on the TV by light sensor is highly questionable. It depends on the type and location of the TV. | |
| 18 | ☑ | Lamps were tested in two distances from the sensor (at 1.3 m and 2.7 m). The closer lamp produced 9.8 lx difference (31 output value), the other one produced 3.3 lx difference (15 output value). When combined, the summarized difference in the illuminance was 14 lx (around 50 output value), which is possible to detect with the sensor. It is highly dependent on the placement of the device and also on the light source type. Needs to be set and be tested individually on site. | |
| 19 | ~ | The temperature drop is not visible in the moment when the window is opened, the temperature is dropping slowly in time instead. The observed temperature drop in winter is 1 °C in 3 minutes (measured 8.12.2020). The measured time is in this case longer than in the test case number 9 and 10, because the cold air is heavier than the warm one, and it is filling the room from the bottom. This time constant is not implemented yet, but can be done in near future. | |
| 20 | ~ | | |
| 21 | ☒ | Boiling water from electric kettle has not changed the output values of the humidity sensor. | |
| explanatory note | | ☒ - Failed ~ - Limited ☑ - Passed | |

**Note:**

The AP7-H version of AP-NURSE Home proved to be the most efficient for movement detection with partial functionality of detecting the basic differences in illuminance and detecting smoke. It also open possibilities for the utilisation of temperature sensors.

**Additional test - Multi-node configuration**

So far, all tests have been carried out for a single base and a single wearable. However, situations in which several bases should be connected into a single wearable may occur. For this purpose, following situation of multi-node configuration was developed on the testing site:

- Node 1 – version AP1-H – placed in the room under the bed in the night mode
- Node 2 - version AP4-H - monitoring hallway in the night mode

This quick test proved, that this functionality is possible and it is working properly. There is, however, one practical issue. When the caretaker wants to turn the alarm off, he/she will have to find the node which is producing the alert.

#### 4.3.2.1.1. Conclusion:

It was found out, that all tests were strongly dependent on the location of the base and also on the sensor sensibility. If the sensor was working to larger distances, the positioning of the device was less relevant and vice versa. The final result of the testing is pointing out gaps in the developed system and also points out that every device needs to be installed and tested properly before any further use.

The summarized main facts about the used sensors are as follows:

- **Noise**
  - No proper communication with the ESP8266 board
  - Excluded from any other tests and AP-NURSE Home versions
- **Smoke**
  - Detecting smoke in various concentrations
  - Effective only in close distances
- **Gas**
  - Detecting various gases
  - Effective only in close distances
- **Light**
  - Output values differ based on the light source
  - Effective when correctly adjusted and placed
- **Force / pressure**
  - Output values differ when not perfectly placed under the patient's mattress
  - Suggestion to use more sensors, or longer sensor to maximize the monitored area
- **Temperature**
  - Output values match the temperature in the room
  - Slow response to temperature drop and increase, time constant needs to be implemented
- **Humidity**
  - Does not produce any alerts
  - Additional functionality for monitoring the environment quality

All possible sensoric states are as follows:

- **PIR**
  - Movement detection = 0 / 1
- **NOISE, LIGHT, SMOKE, GAS, FORCE**
  - Parameter detection = 0-255
- **BME**
  - Contains humidity and temperature sensor
  - Output values are actual humidity and temperature in the room

Timers which need to be implemented in the future:

- **Mute**
  - Time from muting the device before sending alert notifications again
- **Holding abnormal conditions**
  - How long will the alert of an abnormal condition be active
- **Holding critical conditions**
  - How long will the alert of a critical condition be active
- **Stuck timer delay**
  - How long the patient stays in the bathroom
- **Temperature rise / drop constant**
  - Time constant which represents the maximum rise of 1 °C in the room per given time

The summary of testing results as well as the basic settings of the sensors are listed is in **Table 23.**

**Table 23: Summary of the cases - basic settings of the sensors**

| Device | AP-NURSE Home | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Version | **AP1-H** | | **AP7-H** | | **AP2-H** | | **AP4-H** | | **AP6-H** | |
| | Threshold values | | | | | | | | | |
| | Day | Night | Day | Night | Day | Night | Day | Night | Day | Night |
| **Noise** | SI | SI | SI | SI | SI | SI | SI | SI | SI | SI |
| **Smoke** | 20 | 20 | 20 | 20 | SI | SI | SI | SI | 20 | 20 |
| **Gas** | 130 | 130 | 130 | 130 | SI | SI | SI | SI | 130 | 130 |
| **Light** | SD | 50 | SD | 50 | SI | SI | SI | SI | SD | 50 |
| **Pressure** | SI | 70 | SI | SI | SI | SI | SI | SI | SI | SI |
| **Temp** | 1 °C / 3 min | 1 °C / 3 min | 1 °C / 3 min | 1 °C / 3 min | SI | SI | SI | SI | 1 °C / 3 min | 1 °C / 3 min |
| **Humidity** | SI | SI | SI | SI | SI | SI | SI | SI | SI | SI |

**Explanatory notes:**

- SD – sensor disabled
- SI – sensor inactive

#### 4.3.2.2. AP-NURSE Care

##### 4.3.2.2.1. M5Stack

The test cases were carried out in accordance with **Table 9.** The protocols shown in

**Table 18 - Table 21** represent the results achieved in the testing environment. The testing procedure is illustrated in **Figure 64** and **Figure 65.**

**Table 24: Test cases protocol for AP-NURSE Care AP1-M version**

| Device: | AP1-M | Date: | 20.1.2021 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Nuclear and Physical Engineering | Name: | Matej Cenký |
| Test case | | | |
| Number | Result | Notes | |
| 1 | ~ | Motion sensor is reacting to all movement as designed, the only possible issue is the placement under the bed, so the whole area could be monitored. There is an alternative to use two devices with PIR sensors under the bed. The sensrors should be set individually on site. | |
| 2 | ~ | | |
| 3 | ☒ | Gas sensors are placed in great distance from the possible source of smoke. The output values of the sensors did not change during the test sufficiently. However, BME680 is capable of air quality moniyoring, which could be implemented in future applications. | |
| 4 | ☒ | | |
| 5 | ☑ | Force / pressure sensor is sensitive on misplacement. When placed properly (under the body), it works as expected. Default output values when the bed was empty were aproximatelly 2500, when under lying person around 4000 (maximum value), depending on the position of the patient with respect to the sensor. To maximize the effect, multiple force sensors are suggested or at least longer sensor to cover larger area under patient. Needs to be set individually on site. Threshold for triggering up the leave of patient was output value under 3000 over more than 5 seconds. | |
| 6 | ☑ | Motion sensor is reacting to all movement as designed when placed properly. Needs to be set individually on site. | |
| 7 | ☒ | The temperature drop is not visible in the moment when the window is opened, instead the temperature is dropping slowly in time. Observation data are that drop in winter is 1 °C in 2 minutes (measured on 8/12/2020). This time constant is not implemented yet, but is planned in the near future. The current solution supports triggering the alarm at a fixed temperature. Needs to be calibrated before use. | |
| 8 | ☑ | | |
| 9 | ☒ | Boiling water from electric kettle has not changed the humidity sensor output values. Alarm is not triggered. | |
| explanatory note | | ☒ - Failed ~ - Limited ☑ - Passed | |

**Note:**

The AP1-M version of the AP-NURSE Care device proved to be the most efficient for movement detection of the patient around the room and leaving from from bed. BME680 is efficient in temperatures reading and can be applied as air quality monitor in the future.

**Table 25: Test cases protocol for AP-NURSE Care AP2-M**

| Device: | AP2-M | Date: | 20.1.2021 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Nuclear and Physical Engineering | Name: | Matej Cenký |
| Test case | | | |
| Number | Result | Notes | |
| 10 | ☑ | ToF sensor is most efficient when placed against wall, or other flat object from which the signall can be bounced back to sensor. If it is not the case, the sensor sensitivity is lowered considerably. | |
| 11 | ☑ | | |
| 12 | ~ | Triggering the alarm is not always possible because of the limited settings in the IS. Furthermore, if the patient is caught by sensor only when leaving the bathroom, the false alert occurs. It is highly dependent on the ToF sensor reliability. | |
| 13 | ~ | | |
| 14 | ~ | Similar to Test cases 12 and 13, it is highly dependent on the ToF sensor reliability, with risk of false alarm occurrence. | |
| 15 | ~ | | |
| explanatory note | | ☒ - Failed ~ - Limited ☑ - Passed | |

**Note:**

The AP2-M version of AP-NURSE Care proved to be the most efficient for simple movement detection when only narrow observing area is needed.

**Table 26: Test cases protocol for AP-NURSE Care AP4-M**

| Device: | AP4-M | Date: | 20.1.2021 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Nuclear and Physical Engineering | Name: | Matej Cenký |
| Test case | | | |
| Number | Result | Notes | |
| 16 | ☑ | OK | |
| 17 | ☑ | OK | |
| 18 | ☑ | OK | |
| 19 | ☑ | Movement sensor working properly, it needs to be set individually on site. | |
| explanatory note | | ☒ - Failed ~ - Limited ☑ - Passed | |

**Note:**

The AP4-M version of AP-NURSE Home is working properly and is applicable for monitoring the hallway.

**Table 27: Test cases protocol for AP-NURSE Home AP6-M**

| Device: | AP6-M | Date: | 20.1.2021 |
|---|---|---|---|
| Test site: | Slovak University of Technology in Bratislava<br>Faculty of Electrical Engineering and Information Technology<br>Institute of Nuclear and Physical Engineering | Name: | Matej Cenký |
| Test case | | | |
| Number | Result | Notes | |
| 20 | ~ | BME sensor gas output values for gas monitoring are strongly dependent on device placement in the room (observed values from circa 50 000 to 120 000). However, reaction to $CO_2$ or similar gases changes the output rapidly. If placed correctly (in the place of high probability of smoke or gas leak), the sensor was observed to drop its output at least 30 000 units down in a few seconds. Output values droped even to 0 in cases of direct smoke from burned paper nearby. The current solution support fixed output value of the sensor, which should be sufficient in most of the cases. Needs calibration before usage and proper placement. | |
| 21 | ~ | | |
| 22 | ☑ | OK | |
| 23 | ☑ | Light sensor alert trigger was after function tests set to fixed value of 2500 output units, which was sufficient to recognize turned on lamp in the room. | |
| explanatory note | | ☒ - Failed ~ - Limited ☑ - Passed | |

**Note:**

The AP6-M version of AP-NURSE Home is working properly for light and movement monitoring. The possibility to detect gases strongly depends on the source of gases and the placement of the AP-NURSE device.

#### 4.3.2.2.1.1. Conclusion:

It was found out, that all tests were strongly dependent on the location of the AP-NURSE base and also on the sensor sensibility. If the sensor was working to larger distances, the positioning of the device was less relevant and vice versa. The final result of the testing is pointing out gaps in the developed system and also points out that every device needs to be installed and tested properly before any further use.

The summarized main facts about the used sensors are as follows:

- **Noise**
  - Not implemented in the final AP versions
- **Smoke**
  - Detecting smoke in various concentrations
  - Effective only in close distances
- **Gas**
  - Detecting various gases
  - Effective only in close distances

- **Light**
  - Output values differ based on the light source
  - Effective when correctly adjusted and placed
- **Force / pressure**
  - Output values differ when not perfectly placed under the patient's mattress
  - Suggestion to use more sensors, or longer sensor to maximize the monitored area
- **Temperature**
  - Output values match the temperature in the room
  - Slow response to temperature drop and increase, time constant needs to be implemented
- **Humidity**
  - Does not produce any alerts
  - Additional functionality for monitoring the environment quality

All possible sensoric states are as follows:

- **PIR, ToF**
  - Movement detection = 0 / 1
- **LIGHT, FORCE**
  - Parameter detection = 0-4095
- **SMOKE/GAS**
  - Parameter detection = 0-120000+
- **BME680**
  - Contains humidity, temperature and smoke/gas sensor
  - Output values are actual humidity and temperature in the room
  - Gas sensor has output values without units

Planned to be implemented in the future:

- **Time constant with relative change of observed parameter**
- **Reliable operation manual / best practices recommendations**
- **Improve information system functionality**
- **Offline information system possibility**

The summary of testing results as well as the basic settings of the sensors are listed is in **Table 28.**

**Table 28: Summary of the cases - basic settings of the sensors**

| Device | AP-NURSE Care M5Stack | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Version | **AP1-M** | | **AP2-M** | | **AP4-M** | | **AP6-M** | |
| | Threshold values | | | | | | | |
| | Day | Night | Day | Night | Day | Night | Day | Night |
| **Smoke / Gas** | 30 000 | 30 000 | SI | SI | SI | SI | 30 000 | 30 000 |
| **Light** | SI | SI | SI | SI | SI | SI | SI | 2500 |
| **Pressure** | SI | 3000 | SI | SI | SI | SI | SI | SI |
| **Temp** | 1 °C / 3 min | 1 °C / 3 min | SI | SI | SI | SI | 1 °C / 3 min | 1 °C / 3 min |
| **Humidity** | SI | SI | SI | SI | SI | SI | SI | SI |

**Explanatory notes:**

- **SD - sensor disabled**
- **SI - sensor inactive**

#### 4.3.2.2.2. AP-NURSE Care Waspmote

Due to the delay in the oprogress of the AP-NURSE Care Waspmote, the test cases have not been performed so far. They will be performed in the forthcoming months and the results will be included in the updated version of this report.

### 4.3.3. Sensor snsibility tests

#### 4.3.3.1. AP-NURSE Home

Each sensor on base was tested and measured against an available measuring device of appropriate quantity. The humidity sensor was excluded from the sensor sensibility tests, since no appropriate measurement equipment was available for its verification. The results for each tested sensor are presented in the next sections.

##### 4.3.3.1.1. PIR (movement) sensor

The sensibility of the PIR sensor was tested on various distances and angles. Multiple measurements were carried out for each angle of the sensor. The results are shown in **Table 29.**

**Table 29: Sensibility testing results of PIR sensor**

| Sensor angle [°] | 0 | 45 | 90 |
|---|---|---|---|
| Max detection distance [m] | 7.7 | 5.1 | 0.5 |
| Reliable detection distance [m] | 5.1 | 4.1 | 0.5 |

The *max detection distance* represents the maximum achieved distance from the sensor, when the movement was successfully detected at least once. The *reliable detection distance* represents that the movement at that distance from the sensor was detected always. The area in between the max and reliable detection distance have certain probability to detect the movement. However, it is not advised to place the device further then to the reliable detection distance from the monitored area.

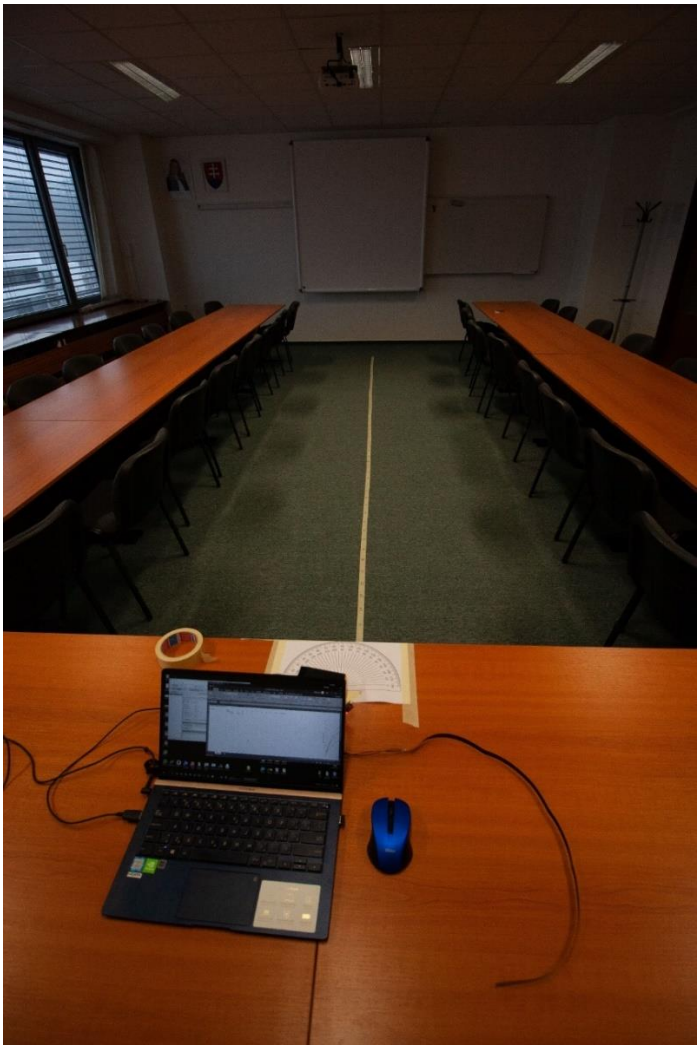


**Figure 66: Setup for experimental measuring of PIR sensor sensitivity**

#### 4.3.3.1.2. Noise sensor

The tests showed that the noise sensor encountered communication issues with the ESP8266 board, resulting in very limited sensibility. The output values of the sensor were basically constant, unless a very large volume difference was achieved (for example extremely loud screaming). This result proved that the noise sensor is not applicable for further testing and was excluded from the AP versions.

#### 4.3.3.1.3. Light sensor

One of the findings of the testing of the light sensor is that the emitting light properties differ for each light source. This behavior resulted also in the different response of the light resulting in different measured

values for each light source. The illuminance of the light sensors was measured in similar conditions, while the measurement with light sensor was conducted.

Together 5 light sources were measured:

- Incandescent lightbulb
- LED
- Compact fluorescent lamp (CFL)
- LCD display (TV / PC / laptop)
- Cloudy weather – direct exposure – placed in the window

The results for each source are shown in **Figure 67**.

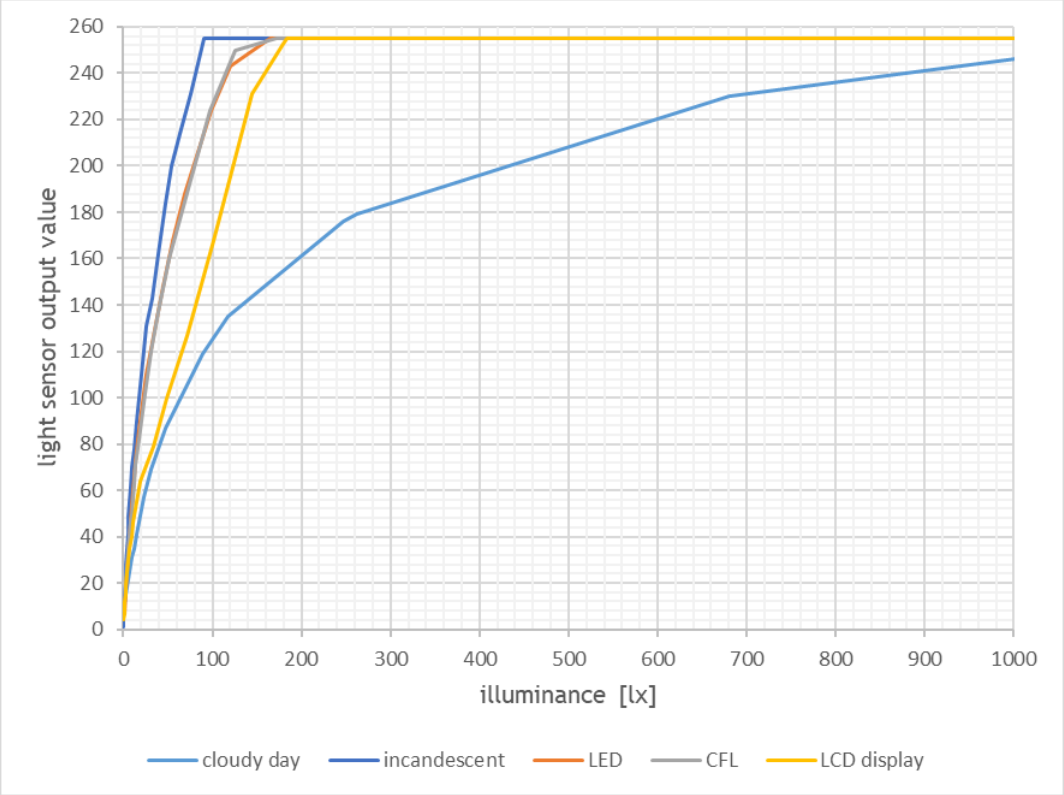



**Figure 67: Measured illuminance against light sensor output value**

As can be seen from the figure above, the light sensor reached the maximum output value (255) at different illuminance for each light source. In case of the light source with the best quality in terms of containing the full spectrum of visible light (heat source), the light sensor got saturated around 90 lx, while in case of the worst light source (LCD display), the saturation of the light sensor was achieved around 180 lx.

The cloudy weather also eliminated the most of the light in the visible spectrum, therefore its sensor output curve is significantly below the others. This is an important finding, which requires different sensor settings for each application, light source and location of the base.

The illuminance in the shadow is up to 50 lx and the illuminance in the direct sunlight is higher than 1000 lx. It can be therefore concluded, that the tested sensor is fully capable of detecting basic light changes in the room when it is placed correctly.

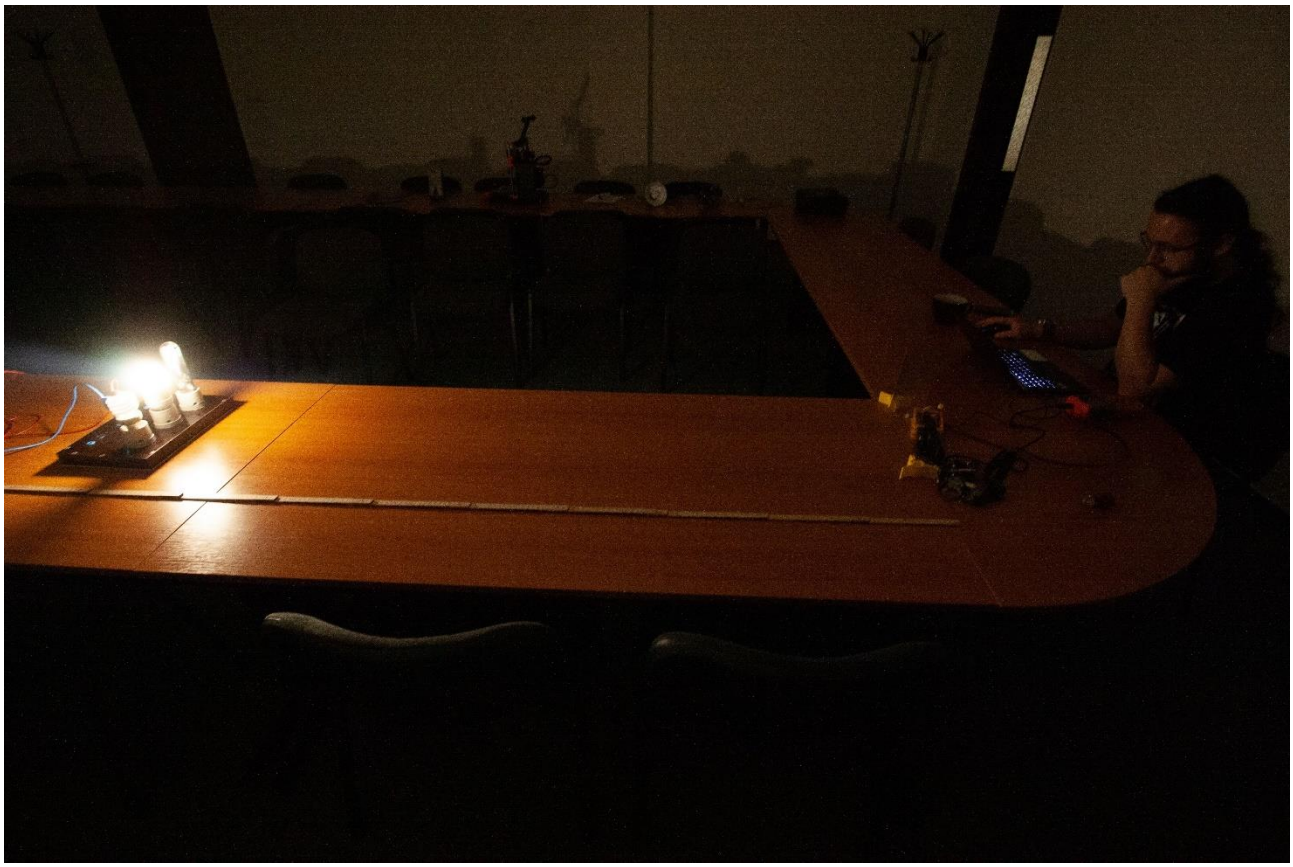


**Figure 68: Experimental measuring the light sensor output**

#### 4.3.3.1.4. Temperature sensor

The temperature sensor was found to be of appropriate precision for the general temperature range (aprox. 10-40 °C), even though its response time is not short. Its placement is however questionable because the BME 280 sensor is placed inside the casing, meaning that it would not be directly in the monitored environment. There are two associated issues:

1. The device itself emits considerable heat that might be detected by the sensor.
2. The sensor is shielded from the room by the casing. Even the casing is partly penetrated for cooling purposes, there are no means of testing how it reacts in case of a sudden temperature drop (opened window in winter) or rise (possible fire).

#### 4.3.3.1.5. Pressure sensor

The pressure sensor is sensible only when direct force is applied to the strip with saturation about 50 N. The placement under the pillow works well, as well as the placement between two pillows. The soft surface is distributing the weight, so it is also applied to the pressure strip, resulting in changing its output value. In case of placing the sensor under the doormat, the results vary depending on the pressure distribution on the doormat (type of doormat + exact standing place). It can be concluded that the tested pressure sensor is a good choice for the purpose of monitoring the patients in the bed, however the sensor should be placed correctly.

#### 4.3.3.2. AP-NURSE Care

##### 4.3.3.2.1. M5Stack

Each sensor on the base was tested and measured against an available measuring device of appropriate quantity. The results for each tested sensor are presented in the next sections.

###### 4.3.3.2.1.1. PIR (moevement) sensor

The sensibility of the PIR sensor was tested on various distances and angles. Multiple measurements were made for each angle of sensor. The results are shown in **Table 30**.

**Table 30: Sensibility testing results of PIR sensor**

| Sensor angle [°] | 0 | 45 | 90 |
|---|---|---|---|
| Max detection distance [m] | 3 | 4 | 1 |
| Reliable detection distance [m] | 2.8 | 3.8 | 0.8 |

The max detection distance represents the maximum achieved distance from the sensor, when the movement was successfully detected at least once. The reliable detection distance represents that the movement at that distance from the sensor was detected always. The area in between the max and reliable detection distance have certain probability to detect the movement. However, it is not advised to place the device further then to the reliable detection distance from the monitored area.

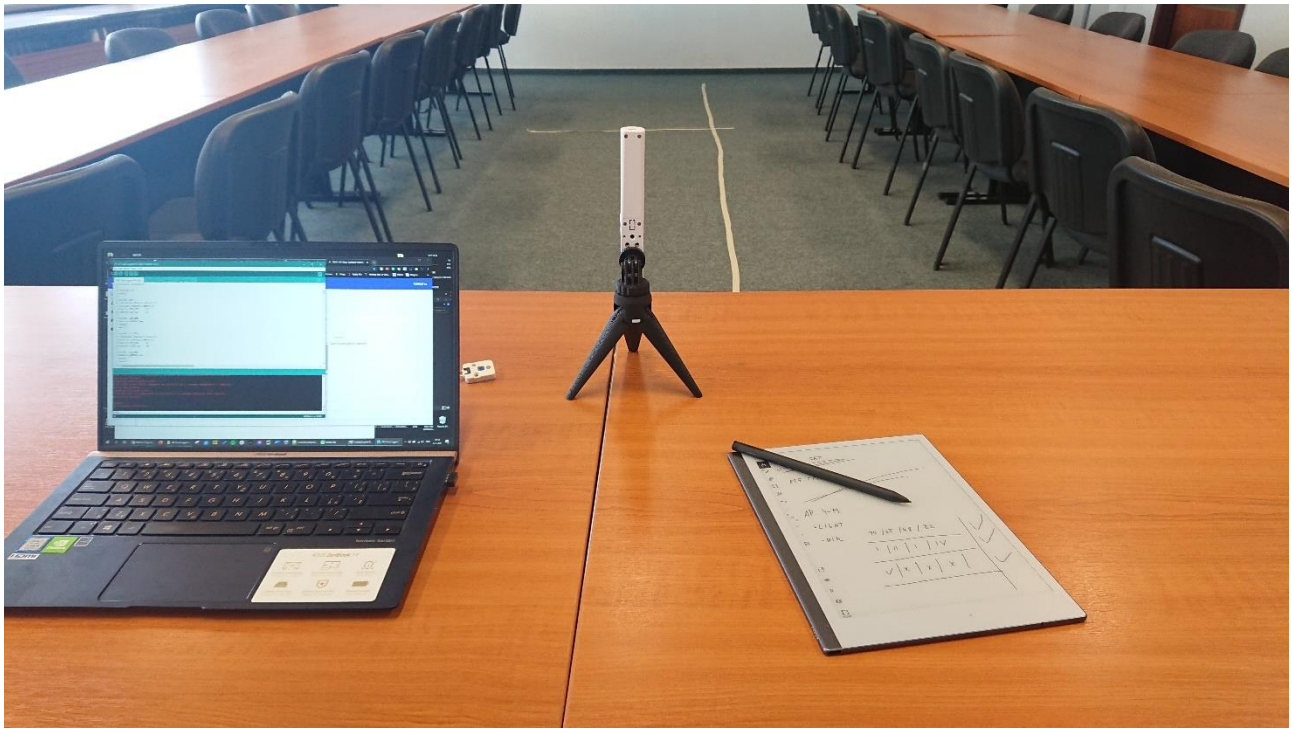


**Figure 69: Setup for experimental measuring of PIR sensor sensitivity**

#### 4.3.3.2.1.2. Light sensor

One of the findings of the light sensor testing is that the emitting light properties differ for each light source. This behavior resulted also in the different response of the light resulting in different measured values for each light source. The illuminance of the light sensors was measured in similar conditions, while the measurement with light sensor was conducted.

Together 3 light sources were measured:

- Incandescent lightbulb
- LED
- Compact fluorescent lamp (CFL)

The results for each source are shown in **Figure 70**.

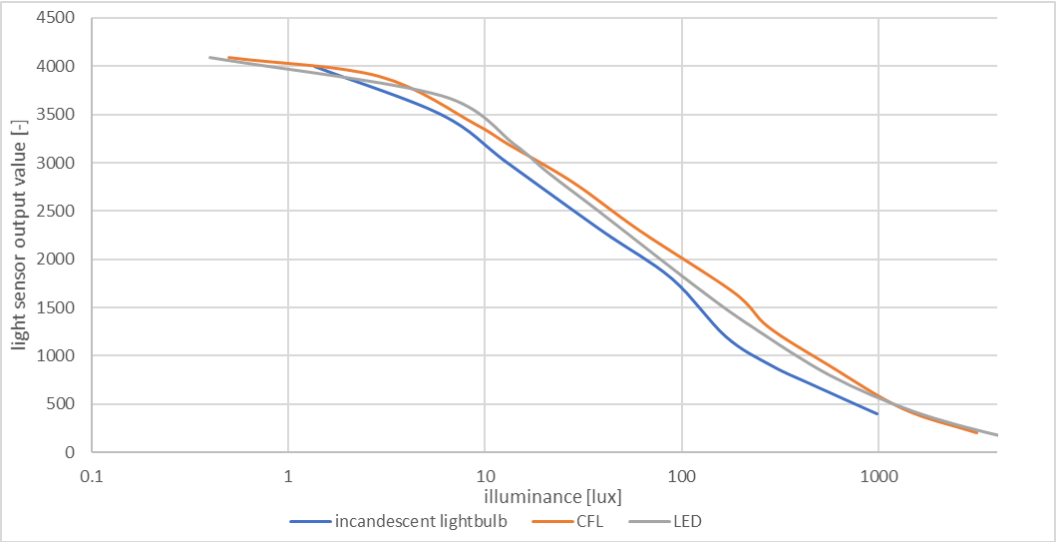



**Figure 70: Measured illuminance against light sensor output value**

#### 4.3.3.2.1.3. Temperature sensor

The temperature sensor was found to be of appropriate precision for the general temperature range (aprox. 10 - 40 °C), even though its response time was observed to be around few seconds, also dependent on the character of the temperature change (faster change – less accurate/slower response; slower change – more accurate response).

#### 4.3.3.2.1.4. Pressure sensor

The pressure sensor is sensitive only when direct force is applied to the strip. Two positions of the sensor were investigated, in both cases, the preasure sensor was places under the single and double layer of matraces:

- Perpendicular postion of sensor to the human body
- Parallel position of preasure sensor to the human body

Results of test are shown in **Figure 71**.

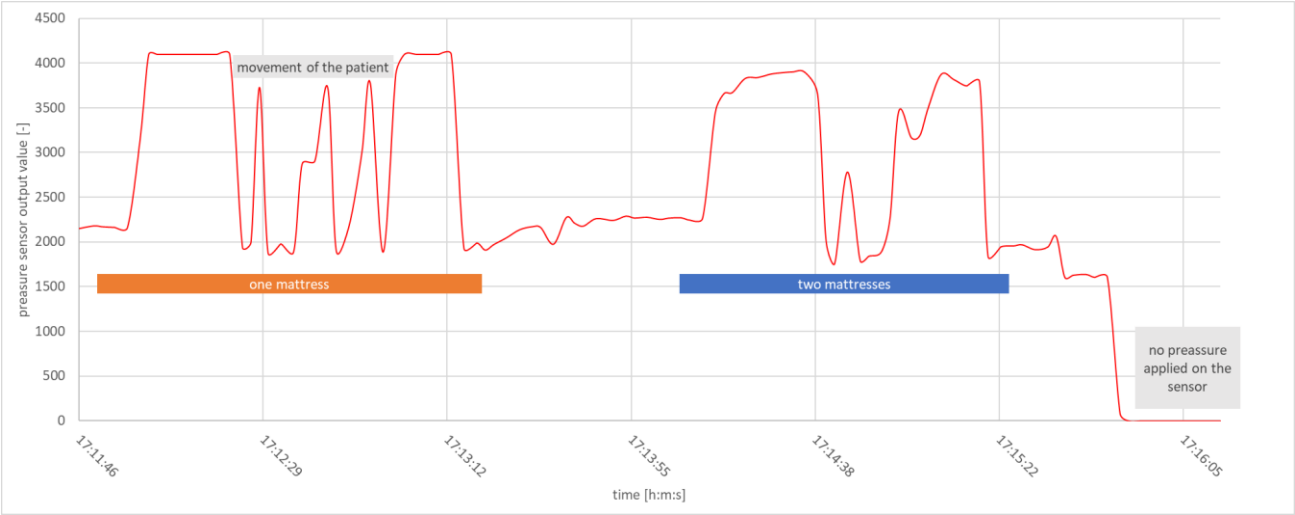



**Figure 71: Measuring of preasure sensor sensitivity**

In all cases the force caused by the weigh of the human body was detected sufficiently. The test subject was a male person with weight 70 kg. Each layer of matraceses was 8 cm thick. It was found out, that in real applications, it is important to place the sensor in the spot where the largest force is applied.

It can be concluded that the tested pressure sensor is a good choice for the purpose of monitoring the patients in the bed, however the sensor should be placed correctly.

#### 4.3.3.2.1.5. Smoke sensor

Smoke sensor is part of the BME680 sensor, which is primarly used for air quality detection. The Gas sensor alone has output units without further recognition of values from aproximately 50 000 to 120 000. The lower value means lower concetration of hazardous gases. The optimal way of detection is relative difference of actual values. This functionality is still in progress on the side of information system. Current solution is fixed alarm trigger. This needs proper calibrating and positioning on site.

The lowest measured values were obtained when sensor was directly aimed to smoke or $CO_2$ source in close distance (circa up to 10 cm). In these cases the output values were droping rapidly ending to be nearly zero.

#### 4.3.3.2.1.6. Humidity sensor

The humidity sensor shows relative humidity. The humidity sensor was excluded from the sensor sensibility tests, since no appropriate measurement equipment was available for its verification.

#### 4.3.3.2.1.7. TOF sensor

The Tof sensor works on the principle of laser beam reflection. Based on the measurements it was found that for the proper functioning of the sensor it is necessary to:

- point the sensor at a surface most perpendicular to the beam
- calibrate the detection sensor for the required distance

In real application the ToF sensor needs to be separately calibrated according the eviroments in witch it is used.

**Figure 72: Experimental testig of ToF sensor**

#### 4.3.3.2.2. AP-NURSE Care Waspmote

Due to the delay in the progress of the AP-NURSE Care Waspmote, the test cases have not been performed so far. They will be performed in the forthcoming months and the results will be included in the updated version of this report.

### 4.3.4. Waspmote preliminary tests

Due to the delay of the procurements of Waspmote components, the testing procedure could not be performed. However a simple testing of the AP-NURSE Care Waspomote components was performed. This process can be divided into the following logical steps:

1. Communication with sensors and reading of their actual value.
    a. The delivered sensors (temperature, humidity and pressure; Hall-Effect sensor; LDR; PIR, gas, sound) were successfully tested utilising analog to digital converter, $I_2C$ bus and event shield attached to the Waspmote board.
    b. The principal functionality of sensors was proofed also when they were all simultaneously attached to the main Waspmote board. The corresponding source code sequences were developed for further needs.
2. Establishment of WiFi connection to the dedicated router.
    a. The WiFi Pro module was attached to the main Waspmote board where the configuration of the module itself was tested.

b. The possibility to join to WiFi network utilising WEP and WPA2 authentication modes, getting and IP, gateway and dynamic IP addresses from the router were successfully tested. The corresponding source code sequences were developed for further needs.

3. Communication over TCP/IP protocol and exchange of internal variables.
    a. The exchange of char variables between Wapmote boards over the TCP/IP protocol was successfully tested.
    b. Following the change of internal variable (e.g. a simple change of internal settings over the network) was demonstrated.
4. HTTP POST to MESHLIUM gateway.
    a. The functionality of accepting POST requests by Meshlium and ability to send frames by Waspmote board with WiFi Pro module through WiFi network by HTTP requests was tested and proofed to be fully functional. The corresponding source code sequences were developed for further needs.
    b. Previously tested sensors where added to the frames sent to Meshlium, where Meshium was successfully able to parse these frames and to store them in the internal MySQL database.
5. HTTPS POST to MESHLIUM gateway.
    a. The functionality described in the previous paragraph was expanded and HTTPS requests were successfully generated and accepted on the Meshlium side (see **Figure 73**).
    b. Certification configuration on the Waspmote board side was tested, where the self signed certificate was in appropriate format exported from the Meshlium itself.
    c. Encrypting of HTTP/S reguest by AES 128 was tested and no faults were identified.
6. Synchronization of MySQL Database with external service.
    a. Interfacing Meshlium with 3rd party cloud services utilising built in Cloud Connectors was successfully tested with the Internet of Things Application Platform and Marketplace of extensible IoT Applications (scripit.io) cloud solution and HTTP.

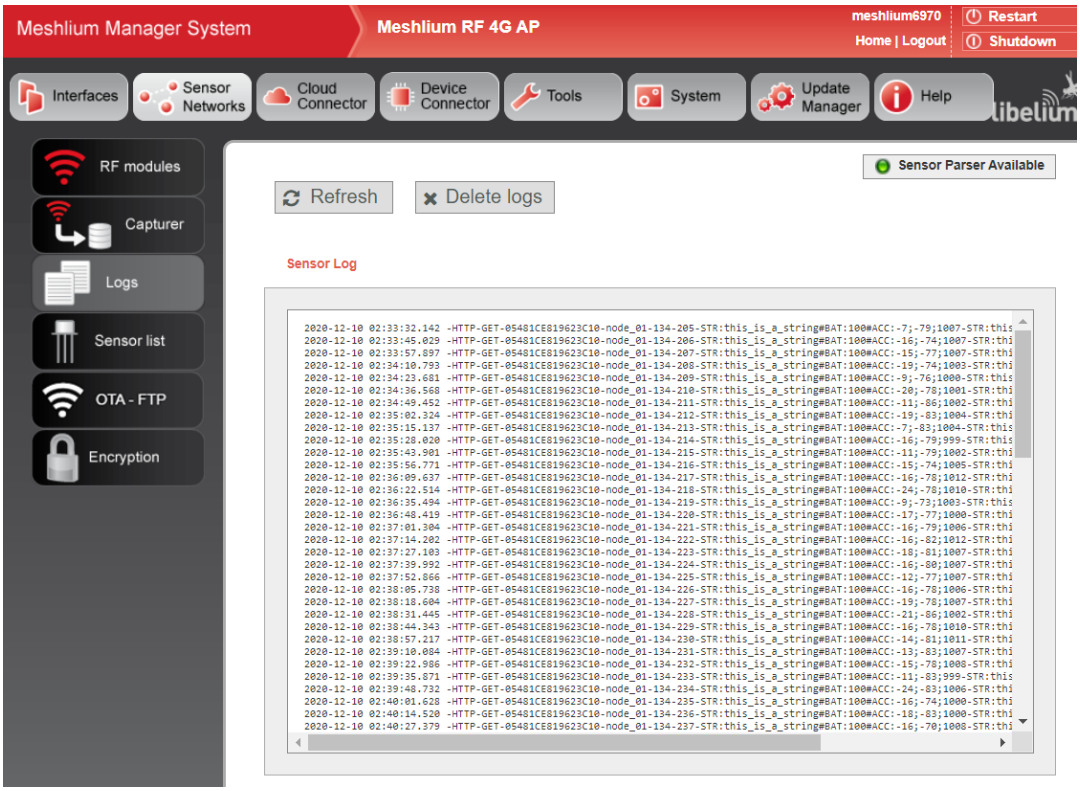


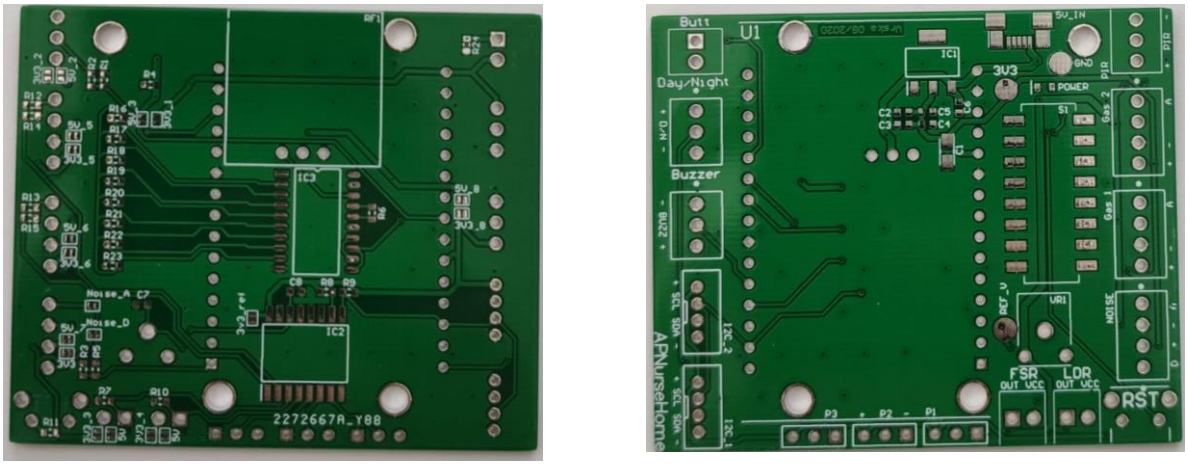

**Figure 73: Meshlium HTTPS request logger**

# 5. AP-NURSE prototype production

## 5.1. PCB manufacturing and component mounting

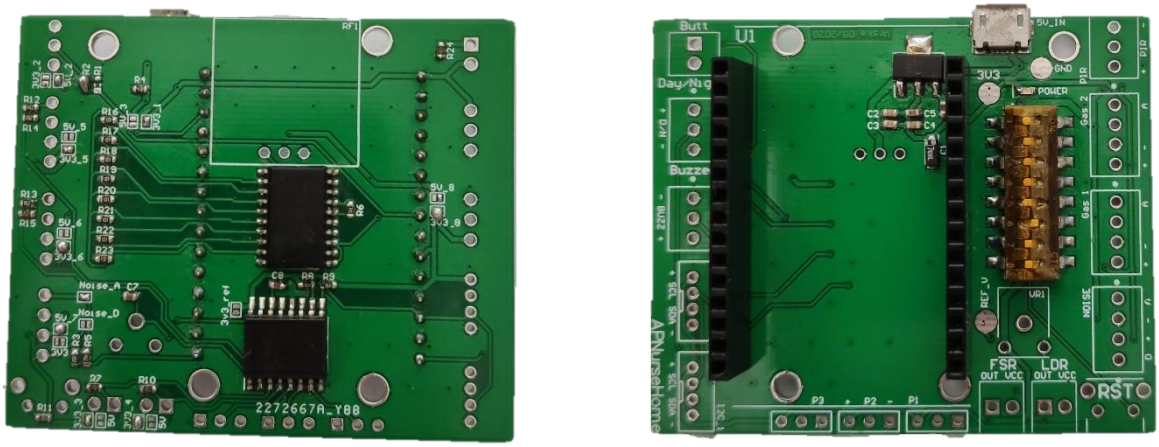
### 5.1.1. AP-NURSE Home

The whole production process of AP-NURSE Home devices is divided according to individual PCB boards for the AP-NURSE Home base shown in **Figure 74** - **Figure 76** and the AP-NURSE Home wearables shown in **Figure 77**. The production starts with the clean PCB board shown in **Figure 74**. Due to its complexity, the following manufacturing is devided into two steps. In the first step, all SMD components are mounted on the PCB which are shown in **Figure 75**. The second step is to verify the functionality using In-circuit testing which verifies the functionality of the peripherals and the whole process of this testing is described in paragraph 5.4.1.1. After the functionality is verified, all connectors of the peripherals are connected to the board and the whole device is shown in **Figure 76**.




**a; bottom side** **b; top side**

**Figure 74 - AP-NURSE Home base - clean PCB**




**a; bottom side** **b; top side**

**Figure 75 - AP-NURSE Home base - PCB before ICT**

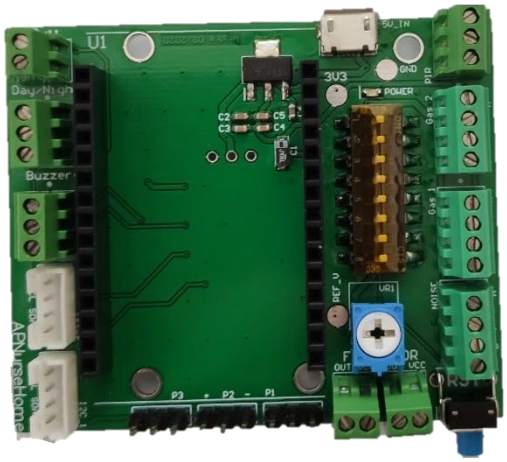



**Figure 76 – Complete AP-NURSE Home base – top side**

Th AP-Nurse Home wearables are created four pieces together, as shown in **Figure 77.** After mounting of the required components the devices are divided into standalone boards.

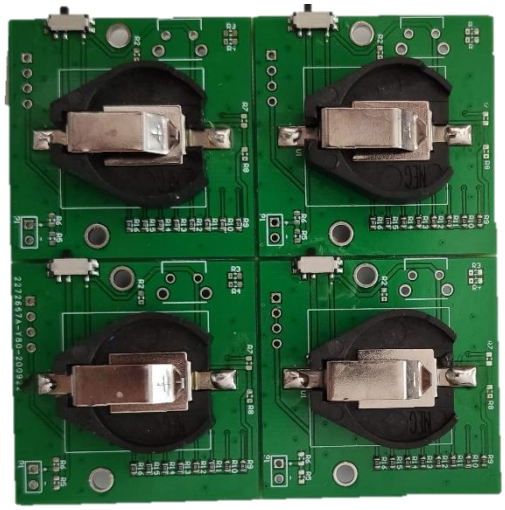
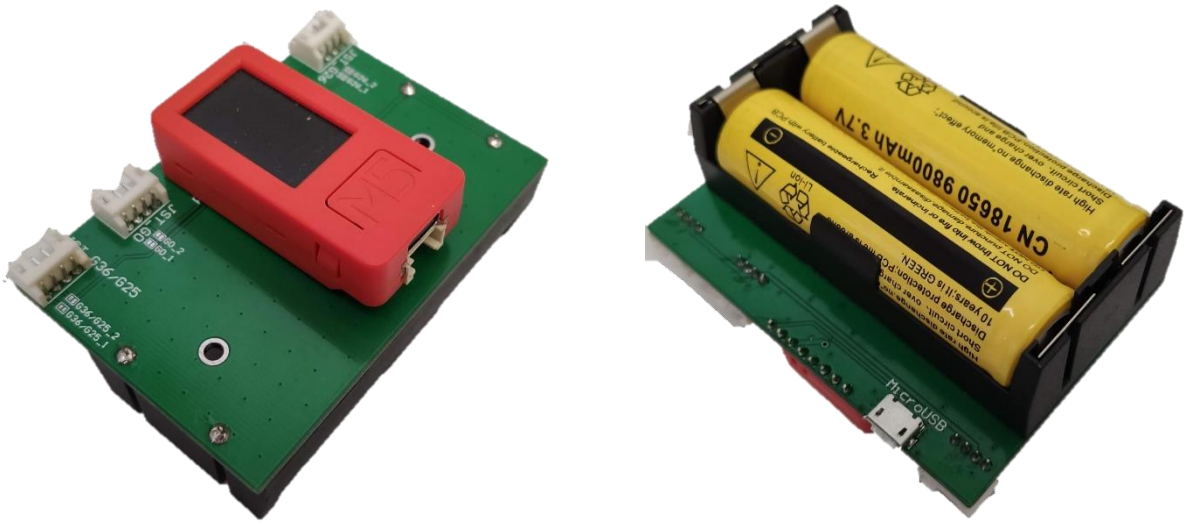


**Figure 77 – Complete PCB board of the AP-NURSE Home wearables**

### 5.1.2. AP-NURSE Care

In terms of the AP-NURSE Care platform, only the battery holder requires PCB production. On this PCB only a few components are mounted and all of them are placed on the board in a few minutes. The final board of the AP-NURSE Care M5Stack battery holder is shown in **Figure 78.**



a; top side b; bottom side

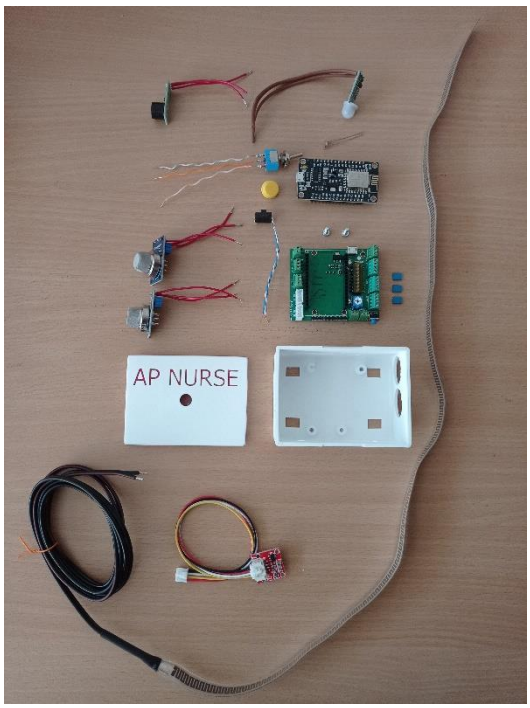
**Figure 78 – Complete AP-NURSE Care M5Stack battery holder PCB**

## 5.2. Device assembling

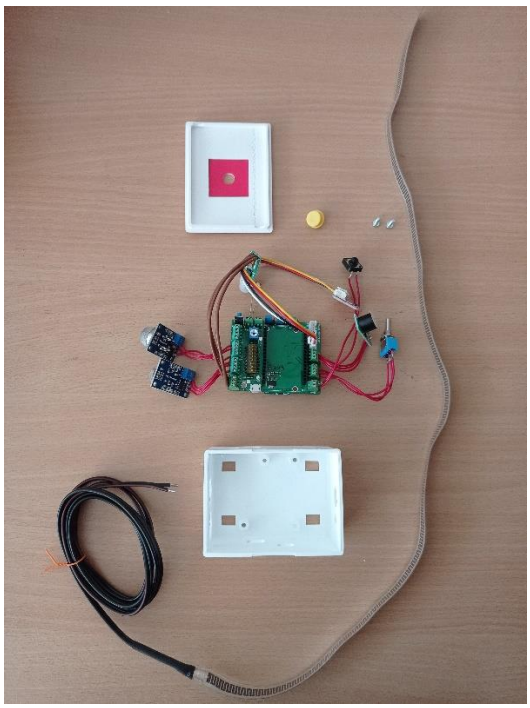
### 5.2.1. AP-NURSE Home

The assembling started with the initial testing of each sensor. After finalizing all tests and ensiring that all component is functioning, the device assembling started. First of all, all the headers from the peripheral sensors and components had to be removed and replaced by cables that provides input connection to the PCB board. All the components that were mounted together are shown in **Figure 79**a .

The jumper headers were placed in the position to setup analog extender for the processing of all analog inputs separately. The MQ-135 smoke and MQ-5 gas sensors were connected to the inputs labelled “Gas1” and “Gas2” on the PCB board. The BME 280 environmental sensor was connected to one of the “I2C” inputs. The connection of the remaining peripherals to theirs assigned headers on the PCB board (i.e. PIR sensor, event button, day/night switch, buzzer, light and force sensor) was straightforward. The assembled PCB board is shown in **Figure 79b** .




a: components for assembling

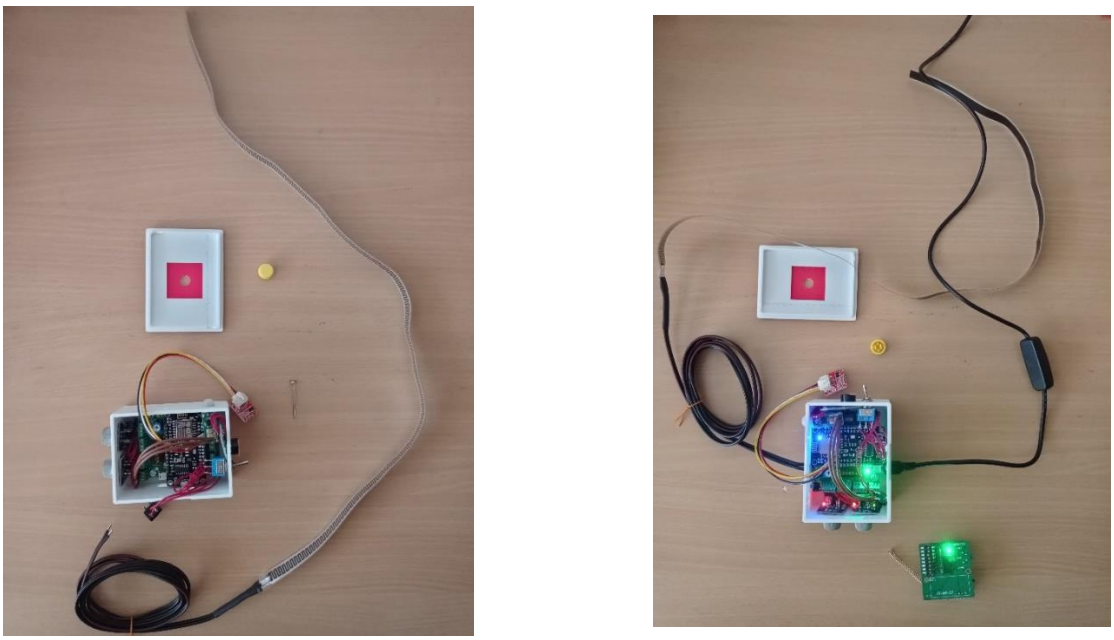


b; PCB with connected peripherals

**Figure 79 – AP-NURSE Home assembling**

To insert the PCV into the casing, first the gas and smoke sensors were inserted to their openings. Afterwards, the PCB board was gently pushed inside the casing and correctly positioned by the restart button and its proper opening in the casing. With this manner, the PCB board was aligned with the spacer pillars on the bottom part of the casing to avoid any damage of the RF 433 MHz transmitter. Next, position of the PCB board in the casing (right upper and left lower spacer pillars were used for the securing of the position) was stabilized by two screws. Subsequently, the ESP8266 board was connected the PCB board bed. The last step was the insertion of the day/night switch, the buzzer and the PIR sensors to theirs opening. The inserted PCB board into the casing is shown in **Figure 80**a.

The force and light sensors were the last two peripherals that were connected to the device. The light sensor contacts had to be shortened for the proper docking into the casing. Subsequently the RF transmission and brief test of the assembled device was conducted to determine, if the device was correctly assembled without any short circuits (**Figure 80**b).



a; PCB in the casing

b; devices assembling test

**Figure 80 – PCB board inserted into the casing**

The final step of the device assembling was the correct encapsulation of the whole device. The environmental BME 280 sensor was placed inside of the casing and the base of the event button was glued to the upper lid of the casing with the sign “AP-NURSE”. The yellow cap was then placed on the baseline of the event button and final device with closed lid is shown in **Figure 81**. The finalized device appears mechanically stable and the opening of the device requires certain force to be applied. Therefore, it can be assumed that whole device prevents any unintentional opening and manipulation during the deployment.


**Figure 81 – AP-NURSE HOME assembled device**

## 5.3. Firmware provisioning

The firmwares of both AP-NURSE Home and AP-NURSE Care M5Stack device were based on the Arduino core, the Arduino build system in complement with the ESP-IDF software development kit. Command line tools used for building the FW image and subsequently flashing the built image to the target device flash. The firmware provisioning process consisted of three stages:

1. Device credentials provisioning
    - During this phase, a set of elliptic curve keys, serial number, and IS credentials for the device is generated based on the device's unique hardware ID.
2. Building of the FW image
    - After all the devices relevant credentials are generated, they are included in the devices FW and its image is built by the Arduino core and ESP-IDF build system.
3. FW upload
    - And last, however not the least, the FW image is flashed onto the target device using a FTDI connection.

All further FW updates are served by OTA FW update is described in chapter 3.2.2.1.

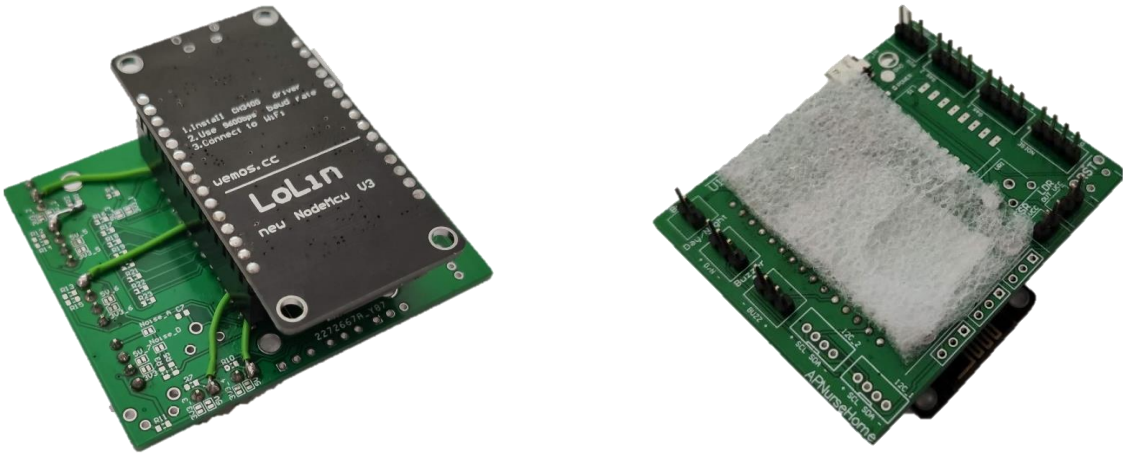
## 5.4. Production tests

### 5.4.1. AP-NURSE Home

Hardware testing is an inherent and important part of any new device production process to ensure reliable operation. Therefore, a set of production tests were established to complement the production process.

#### 5.4.1.1. In-circuit testing (ICT)

After completing the mounting of SMD components on the AP-NURSE Home PCB, each board is connected to an in-circuit testing device shown in **Figure 82**.




**a: bottom side** **b; top side**

**Figure 82 - In-circuit testing device**

This device generates a signal for the individual input pins of the board and examines whether the board evaluates the inputs correctly or not, the whole setup is shown in Figure 83. If the board evaluates all inputs correctly, it is moved to the installation of connectors.

**Figure 83 - In-circuit testing with tested board**

#### 5.4.1.2. Peripheral tests

Before any of the device peripherals are admitted to the assembly process, their functionality is tested using a simple peripheral testing rig shown in **Figure 84**.

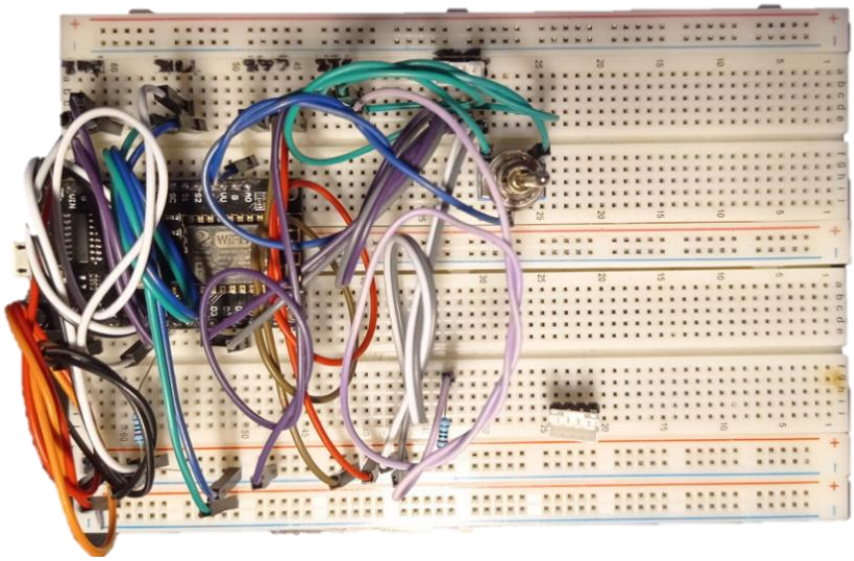
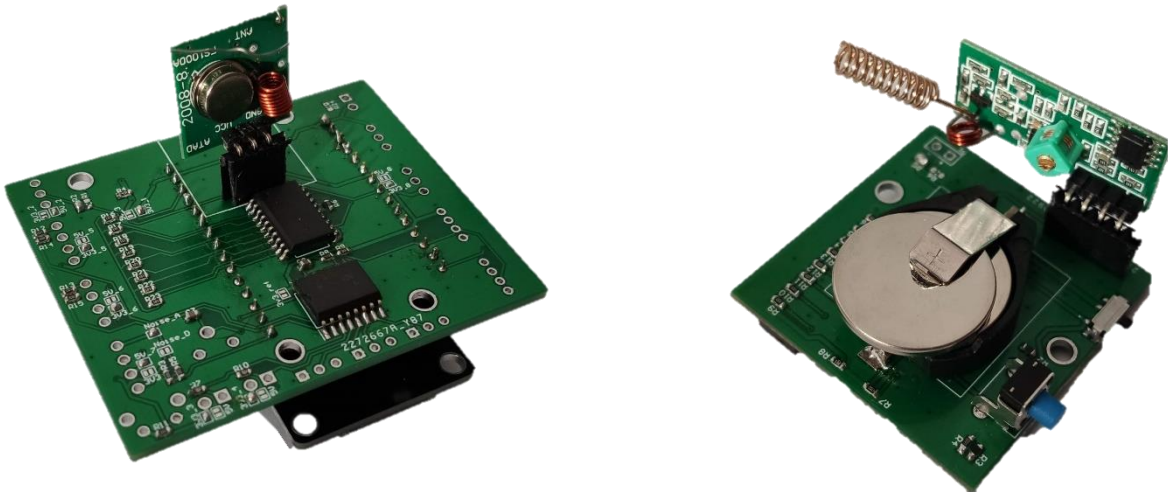


**Figure 84 - Peripheral testing rig**

Here, the ESP8266 reads any of the given peripheral outputs, and analyses them and prints out the test result to a serial monitor. The ESP8266 of the peripheral testing rig also features a LED, which is also used to signalise the test result. However, using the LED signalisation, no multiple peripherals can be tested, therefor the ESP8266 development kit features only 1 LED.

Verification of the functionality of the radio frequency transmitter and receiver is performed by a set of modified AP-NURSE Home boards. Instead of soldering the transmitter and receiver directly to the boards a header connector allows to easily connect them. Then a pre-verified counterpart is used to determine whether the transmitter/receiver is functional. At any given time, only one part of the transmitter/receiver pair is tested to streamline the detection of anomalies in their behaviour. Devices for these tests are shown in **Figure 85**.



a; RF transmitter b; RF receiver

**Figure 85 - RF transmission testing**

# Conclusion

This deliverable summarizes the findings from the laboratory testing and production of AP-NURSE prototypes. It consists of the description of the final design of AP-NURSE Home & Care, the definition of their versions, the results of laboratory testing as well as the details on the assembling procedure and the production of prototypes. The versions of AP-NURSE, selected based needs of potential users, have gone through an intensive and long iteration procedure, which has resulted in 5 versions of the AP-NURSE Home platform (AP1-H, AP2-H, AP4-H, AP6-H and AP7-H), 4 versions of the AP-NURSE Care M5Stack platform (AP1-M, AP2-M, AP4-M and AP6-M) and 2 versions of the AP-NURSE Care Waspmote platform (AP1-W and AP8-W).

Based on the final AP-NURSE versions, the testing methodology was also updated. Due to the delay in the delivery of technical components, the AP-NURSE Care Waspmote platform was not tested yet. The testing of these devices will be performed in accordance with the defined procedure and the results will be collected in the updated version of this deliverable. This document describes the testing of the AP-NURSE Home and AP-NURSE Care M5Stack platforms, including function tests, test cases and sensor sensitivity tests.

For the AP-NURSE Home and Care M5Stack devices 24 as well as 21 function tests were defined. Per each version, several tests had to be omitted, since they required specifics of a different AP version. It should be noted that AP7-H was omitted from testing, since it encompasses the same sensors as AP1-H, but is designed for a different location, but the results of AP1-H also apply for AP7-H. The results of function tests were evaluated as expected and unexpected. The following results were achieved:

- AP1-H – 20 expected results, 0 unexpected results, 4 excluded
- AP1-M – 12 expected results, 0 unexpected results, 9 excluded
- AP2-H - 18 expected results, 1 unexpected results, 5 excluded
- AP2-M - 9 expected results, 0 unexpected results, 2 excluded
- AP4-H - 16 expected results, 1 unexpected results, 7 excluded
- AP4-M - 9 expected results, 0 unexpected results, 12 excluded
- AP6-H - 19 expected results, 1 unexpected results, 4 excluded
- AP6-M - 13 expected results, 0 unexpected results, 8 excluded
- AP7-H – 20 expected results, 0 unexpected results, 4 excluded

The function tests identified very good performance of the AP-NURSE Home and Care M5Stack devices. The average success rate of AP-NURSE Home was 96% and only 3 unexpected results were achieved, each caused by the low sensitivity of the noise sensor. The success rate of AP-NURSE Care M5Stack was 100%.

Subsequently 24 and 15 test cases were defined and performed for AP-NURSE Home and Care M5Stack devices. The tests were evaluated as passed, failed and limited, while the keyword limited represents a case, where under specific circumstances the test could be successful. The following results were achieved:

- AP1-H – 4 passed, 5 failed, 2 limited
- AP1-M - 3 passed, 4 failed, 2 limited
- AP1-W – Will be performed in the future
- AP2-H – 2 passed, 4 failed, 0 limited (lacks implementation of software features)

- AP2-M – 2 passed, 0 failed, 4 limited
- AP4-H – 4 passed, 0 failed, 0 limited
- AP4-M– 4 passed, 0 failed, 0 limited
- AP6-H – 2 passed, 0 failed, 2 limited
- AP6-H – 2 passed, 0 failed, 2 limited
- AP7-H – 6 passed, 2 failed, 2 limited
- AP8-W – Will be tested in the future

It can be seen, that AP2-M, AP4-H, AP4-M, AP6-H and AP6-M achieved 100% pass rate. The lowest pass rates were achieved in case of AP1-H (55%) and AP2-H (33%). The low pass rate of AP2-H was due to the missing implementation of the evaluation logic. The average pass rates of AP-NURSE Home and Care M5Stack devices were 74% and 89%. The average true pass rate (excluding limited tests) was 56% for AP-NURSE Home and 54% for AP-NURSE Care M5Stack. Fails in the test were caused, in the majority of the cases caused, by the humidity sensor, which was not capable of detecting water boiling in electric kettle, the light sensor, which failed to detect TV and the gas sensor, which was placed in a large distance from the possible source of smoke. In addition, AP1-M encountered issued with the motion sensor, which detected all possible movement patterns. Alternatively, two devices with PIR sensors under the bed could be used. The sensors should be however set individually on site. To maximize the effect, multiple force sensors are suggested or at least longer sensor to cover larger area under patient. Triggering the alarm for AP2-M was not always possible, due to the limited settings of the IS. Furthermore, if the patient is caught by sensor only when leaving the bathroom, false alert may occur. The gas output value of the AP6-M BME680 environmental sensor was strongly dependent on device placement in the room.

In general, it should be concluded that the test cases showed useful results and the achieved success rate is acceptable. It was also found out, that all tests were strongly dependent on the placement and also on the sensor sensibility. If the sensor was working to greater distances, the positioning of the device was less relevant and vice versa. The final result of the testing is pointing out the gaps in the developed system and also reveals knowledge, that every device needs to be installed and tested properly before any further use.

The AP-NURSE Home sensor sensibility tests were carried out for the PIR (movement) sensor, noise sensor, light sensor, temperature sensor and pressure sensor. In case of the PIR sensor, it was found out, that is not useful to place the device further from the source than the so called *reliable detection distance* that represents the distance in which the signal was detected in case of each test. The tests of the noise sensor showed that communication issues had been encountered with the ESP8266 board, resulting in very limited sensibility. The output values of the sensor were constant, unless a very large volume difference was achieved. The test of the light sensors showed that the sensor strongly depends on the type and quality of light source therefor its parameters must be set based on the specifics of the real application site. The temperature sensor was found to be of an appropriate precision for the general temperature range (approx. 10-40 °C), even though its response time is not short. Its placement is however questionable because the BME 280 sensor is placed inside the casing, meaning that it would not be directly in the monitored environment. The tests confirmed that the used pressure sensor is a good choice for the purpose of monitoring the patients in the bed, however the sensor should be placed correctly.

The AP-NURSE Care M5Stack sensor sensibility tests were carried out for the PIR movement sensor, light sensor, temperature sensor, pressure sensor, smoke sensor, humidity sensor and TOF sensor. The PIR and light sensor showed similar behaviour as in case of AP-NURSE Home. The temperature sensor was found to be of appropriate precision for the general temperature range (approx. 10 - 40 °C). The tested pressure

sensor is a good choice for the purpose of monitoring the patients in the bed, however the sensor should be placed correctly. The smoke sensor is part of the BME680 sensor, which is primarily used for air quality detection. The Gas sensor alone has output units without further recognition of values from approximately 50 000 to 120 000. The lowest measured values were obtained when sensor was directly aimed to smoke or CO2 source in close distance (circa up to 10 cm). In these cases, the output values were dropping rapidly ending to be nearly zero. he humidity sensor shows relative humidity. The humidity sensor was excluded from the sensor sensibility tests, since no appropriate measurement equipment was available for its verification. In real application the ToF sensor needs to be separately calibrated according the environments in which it is used.

Due to the delay of the procurements of Waspmote components, the testing procedure could not be performed. However, a simple testing of the AP-NURSE Care Waspmote components was performed. These tests included:

- Communication with sensors and reading of their actual value.
- Establishment of WiFi connection to the dedicated router.
- Communication over TCP/IP protocol and exchange of internal variables.
- HTTP POST to MESHLIUM gateway.
- HTTPS POST to MESHLIUM gateway.
- Synchronization of MySQL Database with external service.

Having all tests completed, the porotype production was started. The whole production process of AP-NURSE Home devices was divided according to individual PCB boards for the AP-NURSE Home base and the AP-NURSE Home wearables. The production started with clean PCB boards, continued with mounting of the SMD components and the verification of the functionality using in-circuit testing. In terms of the AP-NURSE Care platform, only the battery holder required PCB production. The assembling of AP-NURSE Home devices started with the initial testing of each sensor. First the headers had to be removed from the peripheral sensors and components and replaced by a cables that provide input connection to the PCB board. When all peripherals and sensor were connected to the PCB, the whole device was encapsulated using the developed casings. Having all hardware issues fixed, the software updates were carried out. The firmware of both AP-NURSE Home and AP-NURSE Care M5Stack device were based on the Arduino core, the Arduino build system in complement with the ESP-IDF software development kit. Command line tools were used for building the FW image and subsequently flashing the built image to the target device flash. The firmware provisioning process consisted of device credentials provisioning, building of the FW image and the FW upload. Finally, a set of production tests were established to complement the production process.

The testing of AP-NURSE devices will continue in care centers, where the final design will be selected based on the achieved results. Based on the achieved results and respecting limitations caused by the COVID-19 pandemic, the finalization of AP-NURSE devices for pilot testing purposes will be performed in next months. The last development a testing stage will be documented in the next deliverables.

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