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AP-NURSE HOME & CARE MONITORING TOOLS

D.T2.2.4 - Testing of Integral Parts of the Modular Tool and Prototype Construction

Version 1
12 2020

1. Introduction

AP-NURSE is a modular and straightforward monitoring tool for patients with Alzheimer's Alzheimer's and Parkinson's disease for home and medical application. It encompasses ambient sensors, which can monitor activity patterns, gas, temperature and sound 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 DT2.2.4 is related to the integral laboratory testing of the AP-NURSE technology and it 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. During the R&D activities and the testing phase, multiple issues were encountered and this reported highlights the most significant ones as well as provides updates on particular designs to fulfil the project objectives.

2. AP-NURSE modifications

2.1. AP-NURSE versions

The initial versions of AP-NURSE, selected based on specific needs of potential users in D.T2.2.3 [2], encompassed 6 versions (AP1-AP6) in case of AP-NURSE Home and 4 versions (AP1, AP2, AP4 and AP6) in case of AP-NURSE Care. Although the selection of these versions played an important part in the design of AP-NURSE devices, the testing phase had identified several issues that resulted in the modifications of initial AP-NURSE versions. The main conceptual changes occurred during the development of the particular test case event trees where the integration of AP1 and AP3 devices into one device. The same applies for AP2 and AP5. These changes are justified since the logic for the mobile and immobile patient is similar, therefore it was no longer necessary to distinguish between application for different patients. An addition, a new AP7 version was created with a purpose, to monitor the patient in the room, when the location of the AP-NURSE devices is not under the bed (as in AP1 or AP3). The modifications of the AP-NURSE versions are listed in Table 1. In the new AP versions the Home and Care M5stack platforms are distinguished by including "H" and "M" in the AP version ID. The detailed overview of AP-NURSE versions can be found in Table 2 and Table 3. It should be noted, that the listed changes resulted also in the modification of the testing procedure. More details can be found in chapter 3 of this document. In the next sections of this report, only the new AP-NURSE version IDs will be used.

Table 1: Modifications of AP-NURSE versions

Initial AP version ID	AP-NURSE version name	New AP version ID	Modifications	Applies for devices
AP1	monitoring device in patient's room under the bed	**AP1-H**	Replaced sensors	Home
		AP1-M	Major changes	Care - M5stack
AP2	monitoring device placed at the doors to toilets in patient's room	**AP2-H**	Replaced sensors	Home
		AP2-M	No	Care - M5stack
AP3	monitoring device in patient's room under the bed	**N/A**	Cancelled	N/A
AP4	monitoring device in common rooms, stairs, forbidden zones for patients	**AP4-H**	Replaced sensors	Home
		AP4-M	Replaced sensors	Care - M5stack
AP5	monitoring device placed at the doors to toilets in patient's room	**N/A**	Cancelled	N/A
AP6	monitoring device in kitchen	**AP6-H**	Replaced sensors	Home
		AP6-M	Replaced and new sensors	Care - M5stack
N/A	monitoring device in patient room (not under the bed)	**AP7-H**	Replaced sensors	Home

Table 2: Detailed overview of the new AP-NURSE Home versions

AP-NURSE Home version	Placement	Device mode	possible event	Sensors						Trigger alert
				Mov.	Force	Noise	Light	Gas	Temp.	
AP1-H	Monitoring device in patient's room under the bed	day	patient got up from the bed	1						✗
		night	walking in the room	1			1			⚠
		night	walking in the room	1						❗
		night	leave bed		drop					❗
		day / night	smoking					1		❗
		day / night	temperature drop						1	❗
		night	TV on				1			⚠
AP2-H	Monitoring device placed at the doors to toilets in patient's room	day / night	entering the bathroom	1						⚠
		day / night	stuck in the bathroom	0=0						❗
		day / night	leaving the bathroom	1						✗
AP4-H	Monitoring device in common rooms, stairs, forbidden zones for patients	night	movement	1						❗
		day	movement	1						✗
AP6-H	Monitoring device in kitchen	day / night	gas leakage / smoke detection					1		❗
		night	movement	1						❗
		night	light				1			⚠
AP7-H	Monitoring device in patient room (not under the bed)	day	patient got up from the bed	1						✗
		night	walking in the room	1			1			❗
		night	walking in the room	1						⚠
		day / night	smoking					1		❗
		day / night	temperature drop						1	❗
		night	TV on				1			⚠

Explanatory notes for sensors:

- ***1*** sensor detects change of state
- ***drop*** sensor detects defined drop of output value
- ***0=0*** sensor detects no change of state for defined time constant

Explanatory notes for trigger alert:

- permitted event, no alert 
- abnormal condition 
- critical condition 

Table 3: Detailed overview of the new AP-NURSE Care M5stack versions

AP NURSE Care version	Application	Device mode	possible event	Sensors							Trigger alert
				Laser	Mov.	Force	Noise	Light	Gas	Temp.	
AP1-M	Under the bed in patients room	day	patient got up from the bed		1						✗
		night	walking in the room		1			1			⚠
		night	walking in the room		1						!
		night	leave bed			drop					!
		night	TV on					1			⚠
AP2-M	Door to toilets or other places	day / night	entering the bathroom	1							⚠
		day / night	stuck in the bathroom	0=0							!
		day / night	leaving the bathroom	1							✗
AP4-M	forbiden places for patients	night	movement		1						!
		day	movement		1						✗
AP6-M	Kitchen	day / night	gas leakage / smoke detection						1		!
		night	movement		1						!

2.1.1. Final configuration of sensors of AP-NURSE Home and Care devices

As it can be seen from the previous chapters, several modifications of the configuration of sensors were carried out. Table 4 and Table 5 present the simplified list of sensors used for the new AP-NURSE versions.

Table 4: Simple list of sensors of the AP-NURSE Home versions

AP-NURSE HOME version	Sensors					
	Mov.	Force	Noise	Light	Gas	Temp.
AP1-H	■	■		■	■	■
AP2-H	■					
AP4-H	■					
AP6-H	■			■	■	
AP7-H	■			■	■	■

Explanatory notes:

- ***Mov.*** movement / PIR sensor
- ***Gas*** both sensor for detecting gases as described in previous sections (MQ-135 and MQ-5)
- ***Temp.*** BME280 temperature sensor

Table 5: Simple list of sensors of the AP-NURSE Care M5stack versions

AP-NURSE CARE version	Sensors					
	Mov.	Force	Noise	Light	Gas	Temp.
AP1-M						
AP2-M						
AP4-M						
AP6-M						

2.2. AP-NURSE Home hardware

The design of the AP-NURSE Home device was prepared in the report D.T2.2.3 [2]. However, during the initial testing of the newly constructed sensor boards (together with functional test and test cases) multiple issues were observed and therefore some changes had to be incorporated in the sensor board design. The most significant change is the connection of the event button to a different pin. Initially, the event button was connected to pin D9 (GPIO3). This connection however required disabling the USB (UART) debugging functionality. Since the absence of the debugging function of the device would make the whole testing process difficult, the developers decided to modify the AP-NURSE Home scheme by connecting the event button to pin D8 (GPIO15) instead of pin D9. This modification is highlighted in Figure 1 by a red ellipse.

The next change was in the selection of the PIR module. The original HC-SR505 version did not perform well during initial testing, particularly the inherent delay constant of the sensor was 8 seconds and could be easily saturated, probably by day light. Also multiple users claimed, that this false generation of positive signal could have been caused by the RF communication. There are two RF transmitters incorporated in the sensor board (RF 433 MHz transmitter and wi-fi module at 2.4 GHz) [3]. It was found out, that also the power supply could interfere with the PIR sensor and thus the developers decided to change this sensor to PIR module 312 (see Table 6). The next change was the modification of the power bank. According to the manufacturer's specification, the previous power bank was claimed to provide the pass-through function that enables continuous charging from the power-outlet. However, during the testing, it was not possible to confirm this functionality, therefore the original power bank was not found suitable for AP-NURSE Home. The EMOS (B0521B POWERBANK ALPHA5) power bank was chosen, where the pass-through function was successfully confirmed also by testing (see Table 6). Additional components and elements were added to the design to increase the safety of the device, such as heat-shrink tube for the feeding cables of the force pressure sensor. The list and specification of updated components can be found in Table 6.

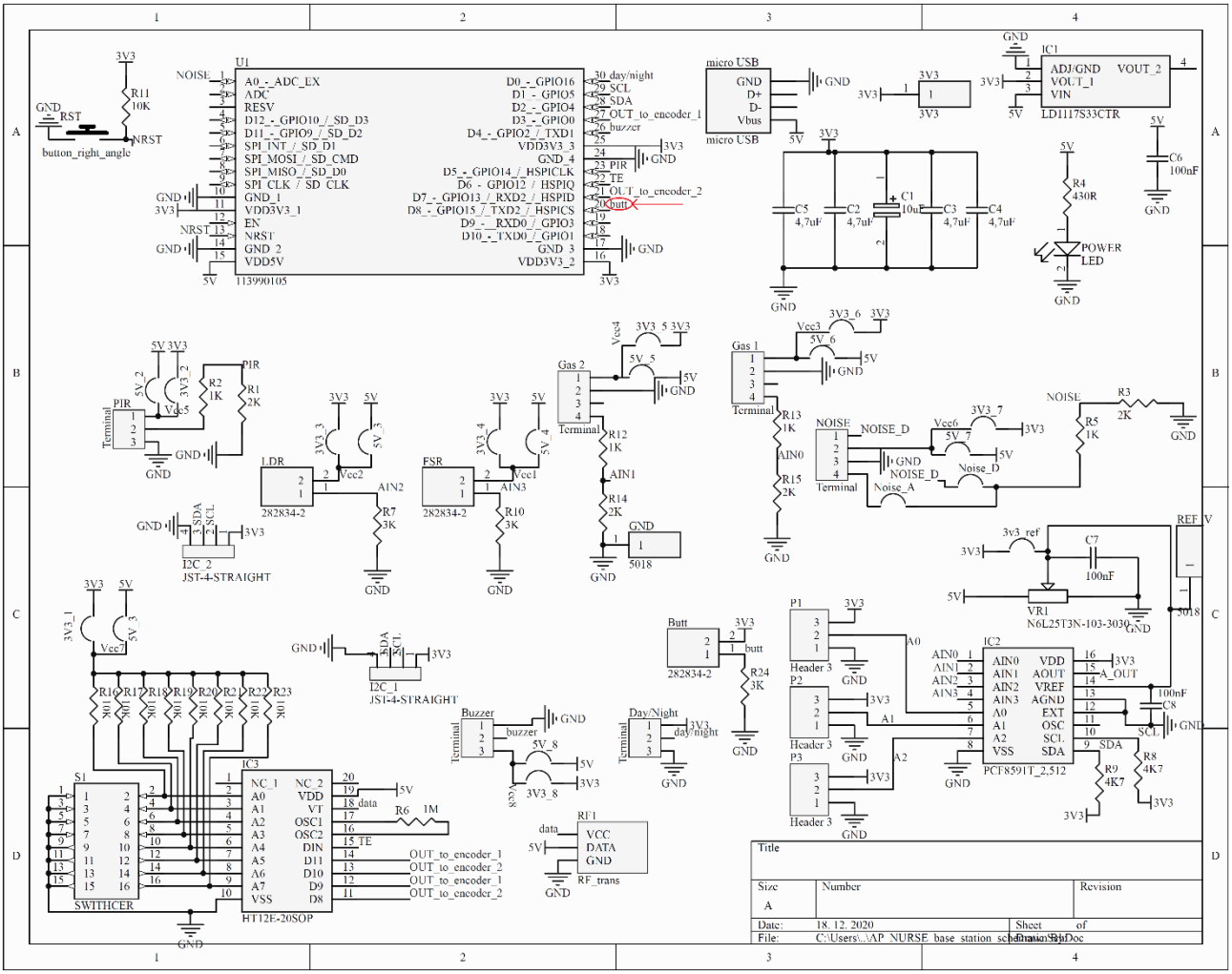

Figure 1: Updated scheme of the AP-NURSE Home sensor board

Table 6: Updated versions of AP-NURSE Home hardware components

PIR module 312 	PIR module 312 is a motion sensor that can monitor the person's presence in the sensing area. The detection range declared by the supplier is 6 meters with the angle 120°. It supports operating voltage range between 2.7 - 12 V with current lower than 0.1 mA [4].
EMOS B0521B power bank 5 000 mAh 	The power bank contains the verified pass-through feature that enables continuous charging from the power-outlet. If loss of power supply in power outlet occurs, the power bank restarts itself and starts to supply the sensor board. The output voltage and current is 5V / 2.1 A DC. The capacity of the battery is 5 000 mAh. The temperature operation range is 0-40°C [5].

2.3. AP-NURSE Home casing

The AP-NURSE Home casing was designed to cover and secure the hardware and to position sensors and buttons. The produced CAD model is simple and possible to print with 3D printers without need to use supports. The design provides easy access to all controllers, sensors and other electronic parts. The top cover is designed as press & click system with no requirements for screwing. All frequent used controllers are accessible from the exterior of the casing box. The positioning of the buttons, sensors and other electronic parts is designed to eliminate the wiring length. The main board is fixed by the screws. Other parts 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 Draw CAD – Print – Test loop process was used to develop the final casing. To date, four iterations were made for the AP-NURSE Home casing (Figure 2a), two iterations for the AP-NURSE battery holder (Figure 2b) and three iterations for the AP-NURSE wearables (Figure 2c).

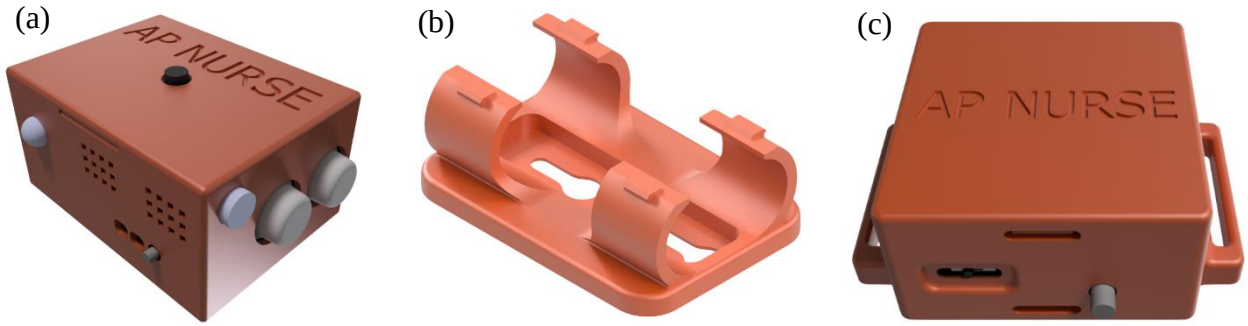

Figure 2 AP-NURSE Home casing (a), AP-NURSE battery holder with the clips for fixation to the AP-NURSE Home casing (b), AP-NURSE wearables casing (c)

2.4. AP-NURSE Care hardware

The changes performed in the AP-NURSE Care hardware are the change of the M5StickC core unit, which is a M5 Mini-CORE based on the ESP32 chip, and the schemes of the AP1-M, AP4-M and AP6-M versions.

2.4.1. M5StickC module

M5stickC is one of the core devices in the M5Stack product series. The main component of all devices is the M5StickC Plus, which replaced the previous M5StickC microcontroller. This new microcontroller has a larger display than the previous one, contains an RTC circuit, a larger flashlight, and a built-in passive buzzer.

Figure 3 The old M5StickC (left) and the new M5StickC Plus (right) devices.

2.4.2. AP1-M scheme

The AP1-M version of AP-NURSE Care, the device that is designed to be placed under the client's bed, has been modified in several directions. The main changes were the addition of an external battery so that the device did not need to be permanently connected to the power source and, in addition, a smoke sensor was connected to the device to detect the possible ignition of the mattress on which the patient lies. The light sensor was removed from the device because the measurement under the bed was not accurate enough. The original and the modified AP1-M configuration scheme is shown in Figure 4.

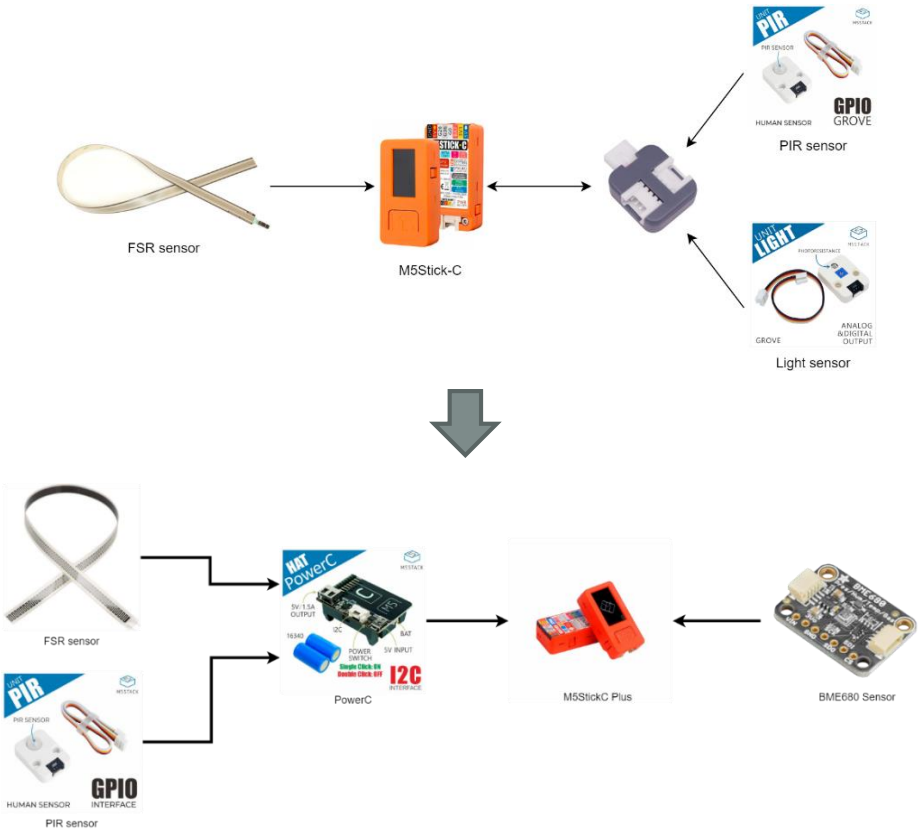

Figure 4: Original and modified AP1-M configuration scheme of AP-NURSE Care

2.4.3. AP4-M scheme

The AP4-M version of AP-NURSE Care, the device designed to be located in the hallway or the common areas, has been modified only by replacing the PIR sensor. The change was from a cable-connected sensor to a push-in sensor, which makes the device easier to use and requires no encapsulation. With the 18650C battery pack, the device can be used without cable charging. The original and the modified AP4-M configuration scheme is shown in Figure 5.

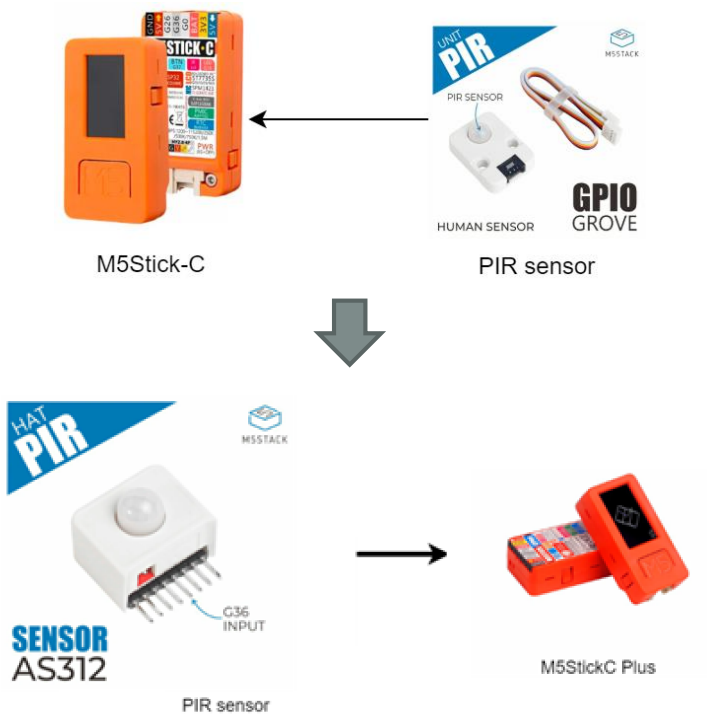

Figure 5: Original and modified AP4-M configuration scheme of AP-NURSE Care

2.4.4. AP6-M scheme

In rooms that are used for cooking, and where the risk of fire is not negligible, the main sensor of the AP6-M version of AP-NURSE Care, which detects smoke in the air, was replaced by a BME680 chip. The capabilities of the new chip are the same as of the original one, but with lower energy consumption and thus longer battery life. A light sensor as well as a PowerC battery pack were added to the device for more functionality and longer battery life. The original and the modified AP6-M configuration scheme is shown in Figure 6.

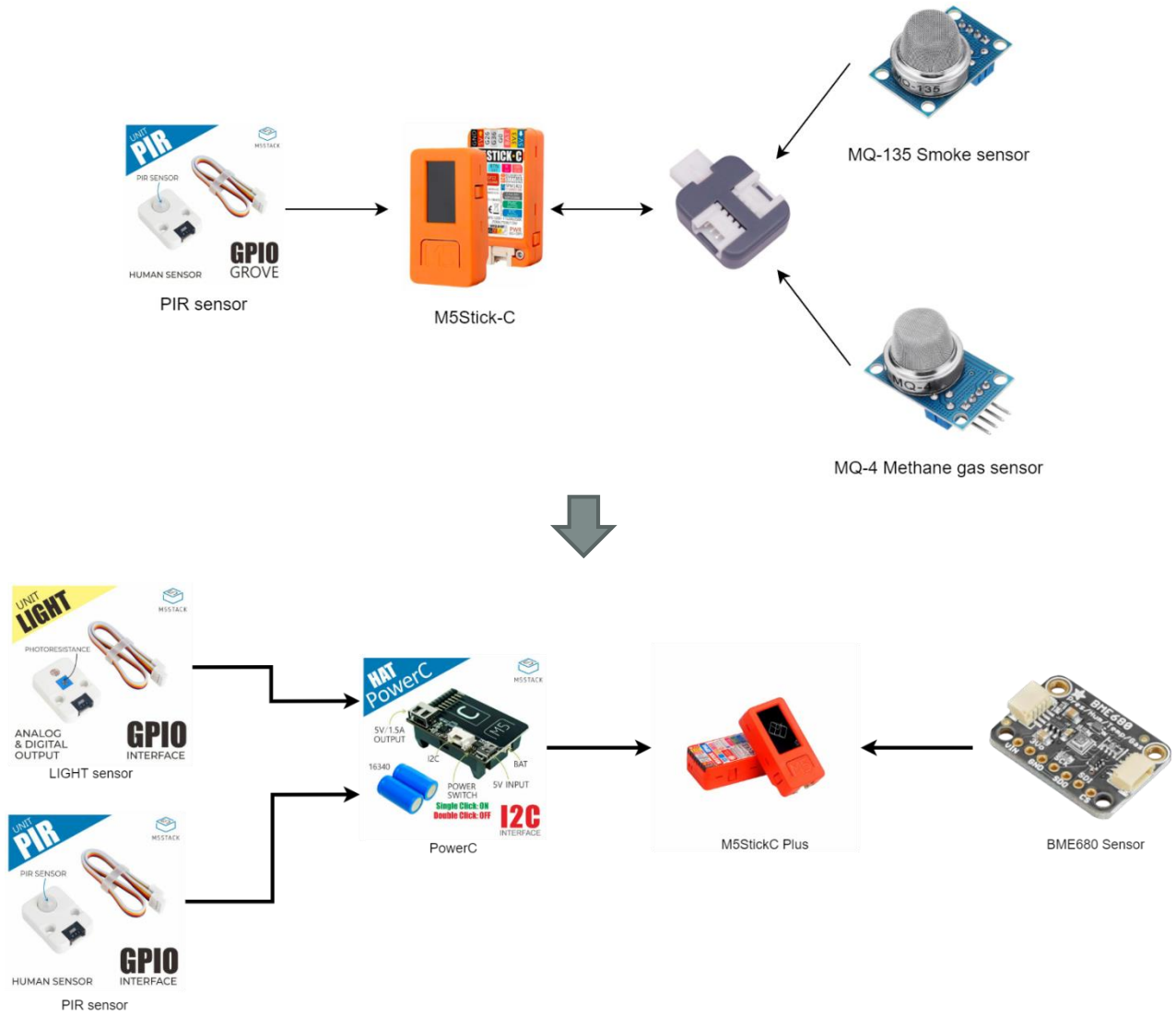

Figure 6: Original and modified AP6-M configuration scheme of AP-NURSE Care

2.5. AP-NURSE Care casing

The AP-NURSE Care casing was designed for the M5stack version of AP-NURSE Care, to cover and secure the hardware and to position sensors and buttons. The produced CAD model is simple and possible to print with 3D printers without need to use supports. The design provides easy access to all controllers, sensors and other electronic parts. The top cover is designed as press & click system with no requirements for screwing. The main board, sensors and other parts 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. AP-NURSE Care casing contains more defaultly covered holes with the removable openings. To date, the first CAD model for AP-NURSE Care is designed and is shown in Figure 7.

Figure 7 AP-NURSE Care casing.

2.6. AP-NURSE Care Waspmote platform

The first components of the Waspmote solution were delivered to STU BA in November 2020. The delivered components consist of Waspmote boards, WiFi Pro modules, antennas, events sensor boards, expansion boards, batteries, dedicated sensors and a Meshlium gateway. However, the second package of necessary components still did not arrive till the end of 2020. Due to the delay of components procurement, the priority of development was given to other technical solutions described in STU BA deliverables. Despite the short development time, significant progress was achieved also with the AP-NURSE Care Waspmote platform based on the delivered components. The exact versions of AP-NURSE Care Waspmote solution will be defined upon laboratory testing of available components, but will in general follow the logic used for the AP-NURSE Care M5stack platform.

3. Testing methodology

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

1. Function tests
2. Sensor sensibility tests
3. Test cases

In addition to the testing procedure defined in D.T2.2.3, a new set of sensor sensibility tests was defined. The new set was added based on the outcomes of the testing to enhance the sensibility and functionality of whole developed device.

3.1. Function tests

3.1.1. AP-NURSE Home function tests

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 8 - Figure 11. There are four basis event flow tests

from which function test were derived. All function test must be performed at least 10 times and the results must be evaluated in the test protocols. The results of the function test performed for each device, are also recorded in a test protocol. In the event flow charts, the following marking are used:

- Grail infill box – sensor board functionality
- White infill box – bracelet board functionality (AP-NURSE Home wearable)

Event flow test 1

Event flow test 1 verifies:

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

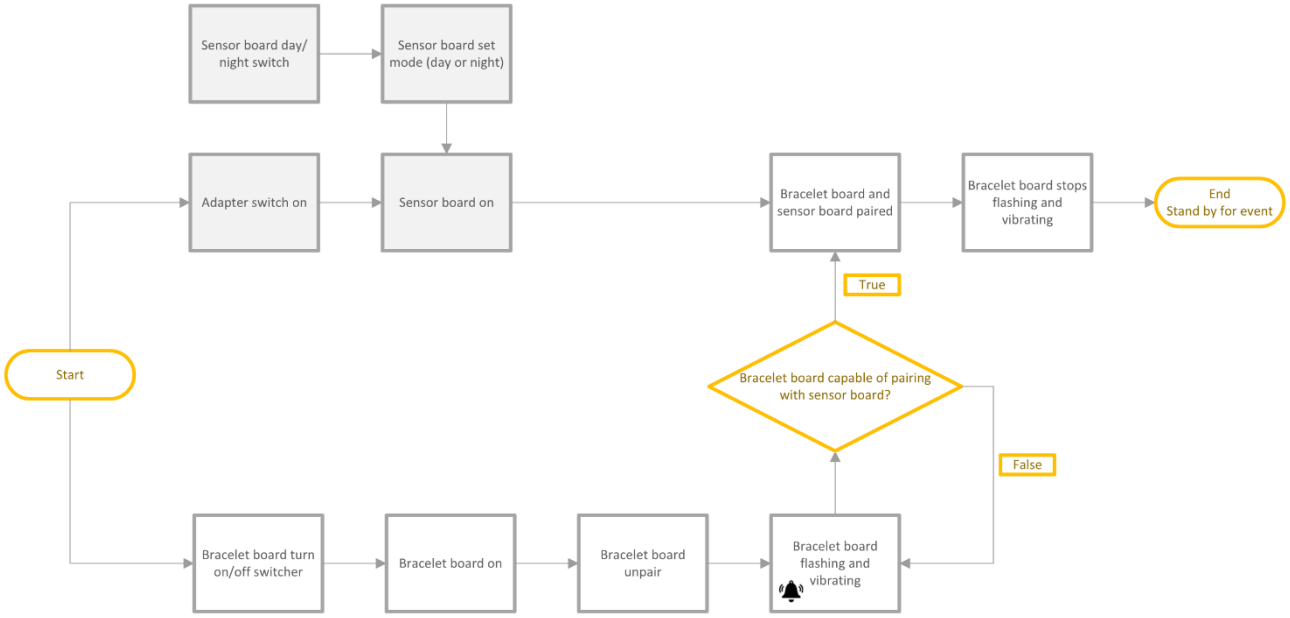

Figure 8: AP-NURSE Home event flow 1

Event flow test 2

Event flow test 2 verifies:

- unpairing due to the loss of signal
    - sensor board turned off
    - sensor board reset
    - bracelet board turn off
- unpairing due to the increase of distance between receiver and transmitter

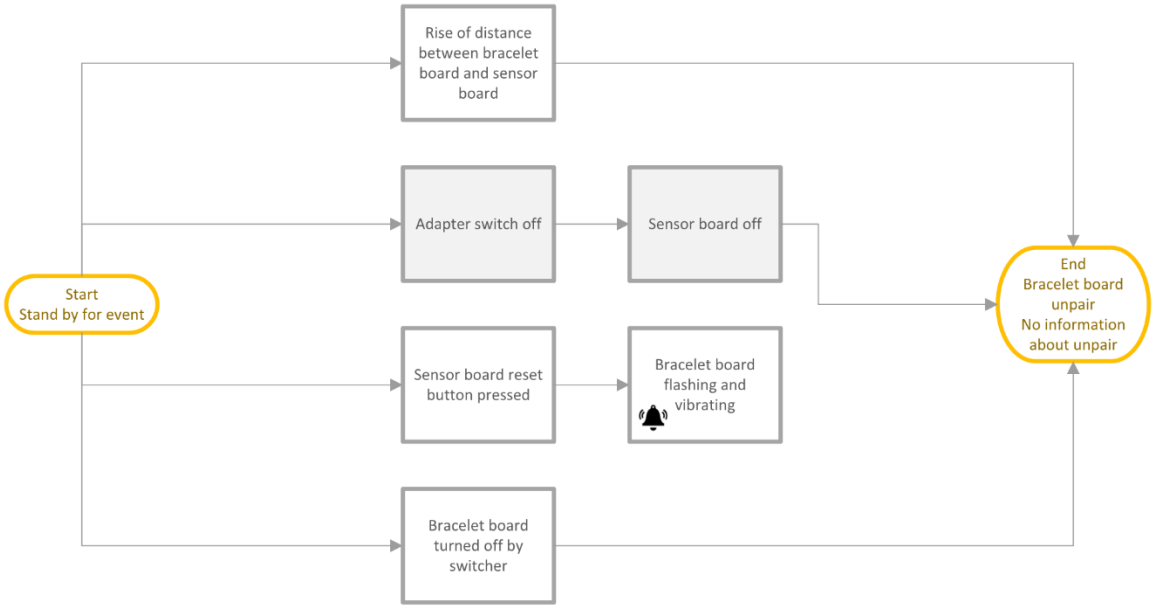

Figure 9: AP-NURSE Home event flow 2

Event flow test 3

Event flow test 3 verifies watch functionality of displaying battery level.

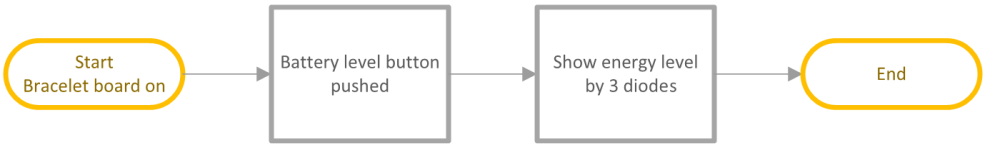

Figure 10: AP-NURSE Home event flow 3

Event flow test 4

Event flow test 4 verifies:

- filtering abnormal condition and critical condition
- day/night event filtering
- abnormal condition/ critical condition alarm trigger
- alarm signalization / alarm muting
- time delay to device to back into stand by regime

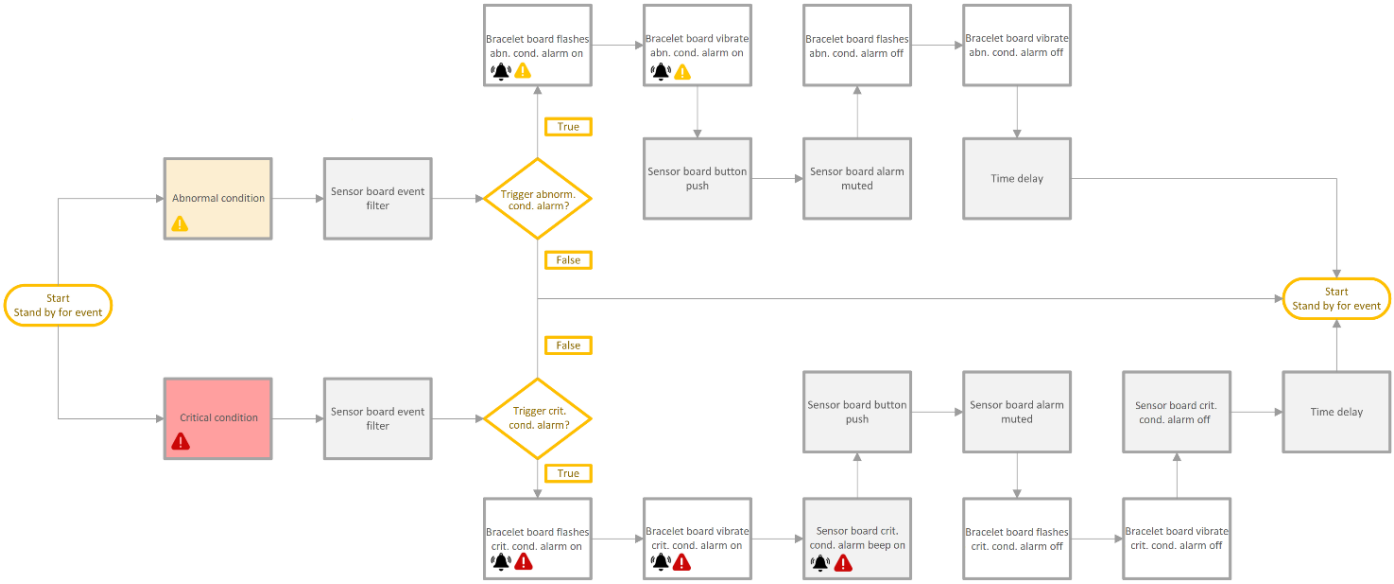

Figure 11: AP-NURSE Home event flow 4

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 bracelet board and sensor board.
- Unpairing distance in case of distance with barriers between bracelet board and sensor board.
- 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 7.

Table 7: Overview and description of function tests of for AP-NURSE Home devices

Test	Initial state	Events					End state	Event flow test number
EFT-H-1	bracelet board off - sensor board box off	sensor board adapter switch on	bracelet board on	bracelet board pair	signalize pairing		stand by	1
EFT-H-2	stand by	sensor board box adapter off, no baterry in sensor board	bracelet board unpair	sensor board adapter on	bracelet board pair	signalize pairing	stand by	1+2
EFT-H-3	stand by	sensor board reset	bracelet board unpair	bracelet board pair	signalize pairing		stand by	1+2
EFT-H-4	stand by	bracelet board off	bracelet board on	bracelet board pair	signalize pairing		stand by	1+2
EFT-H-5	stand by	rise in distance between reciever and transmitter	bracelet board unpair	fall in distance between reciever and transmitter	bracelet board pair		stand by	1+2
EFT-H-6	stand by	sensor board adapter off	sensor board powered from baterry, nothing happends	sensor board adapter on	Bracelet board vibrate		stand by	1+2
EFT-H-7	bracelet board on	click baterry button					show baterry level	3
EFT-H-8	bracelet board on	click baterry button	verify LED signalization of baterry level with actual baterry level by voltage measurement for diferent baterry states				show baterry level	3
EFT-H-9	stand by	trigger abnormal condition	filter event				stand by	4
EFT-H-10	stand by	trigger critical condition	don't filter event	signalize critical condtition alarm	mute critical condition alarm		stand by	4
EFT-H-11	stand by	trigger abnormal condition	don't filter event	signalize abnormal condition alarm	mute abnormal condition alarm		stand by	4
EFT-H-12	stand by	trigger abnormal condition	don't filter event	signalize abnormal condition alarm	mute abnormal condition alarm	time delay	find out best practical time delay	4
ST-H-1	stand by	trigger temperature sensor board					catch abnormal condition	ST
ST-H-2	stand by	trigger humidity sensor board					catch abnormal condition	ST
ST-H-3	stand by	trigger movement sensor board					catch abnormal condition	ST
ST-H-4	stand by	trigger accelerometer sensor board					catch abnormal condition	ST
ST-H-5	stand by	trigger noise sensor board					catch abnormal condition	ST
ST-H-6	stand by	trigger light sensor board					catch abnormal condition	ST
ST-H-7	stand by	trigger gas MQ135 sensor board					catch critical condition	ST
ST-H-8	stand by	trigger gas MQ5 sensor board					catch critical condition	ST
ST-H-9	bracelet board off - sensor board off	20m distance between reciever and transmitter, **no barriers**	sensor board adapter switch on	bracelet board on	lower the distance between reciever and transmitter	bracelet board pair	find out maximum distance for bracelet board to pair with sensor board in case of no bariers between them	ST
ST-H-10	bracelet board off - sensor board off	20m distance between reciever and transmitter, **with barriers**	sensor board adapter switch on	bracelet board on	lower the distance between reciever and transmitter	bracelet board pair	find out maximum distance for bracelet board to pair with sensor board in case of single or several walls between them	ST
ST-H-11	stand by	motion sensor board is mounted in colimator	trigger movement sensor board with different distance and angle of triggering object from movement sensor board				evaluate usage of movement sensor board with collimator for barier detection cases	ST
ST-H-12	stand by	fall of sensor board	trigger giroscope event				evaluate posibility to recognize movement of sensor board	ST

3.1.2. AP-NURSE Care function tests

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 12 - Figure 16. There are five basis event flow tests from which function test are derived. All function test must be performed at least 10 times and the results must be evaluated in test protocols. In the event flow charts the following marking are used:

- Grail infill box – sensor unit functionality
- White infill box – central unit functionality
- Blue infill box – other communication device such as PC or smartphone

Event flow test 1

Event flow test 1 verifies:

- turning on/off sensor unit

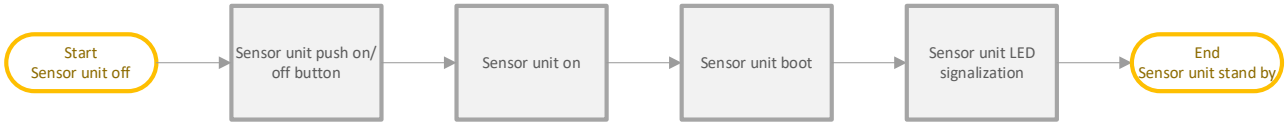

Figure 12: AP-NURSE Care event flow 1

Event flow test 2

Event flow test 2 verifies:

- turning on central unit
- pairing central unit with sensor unit

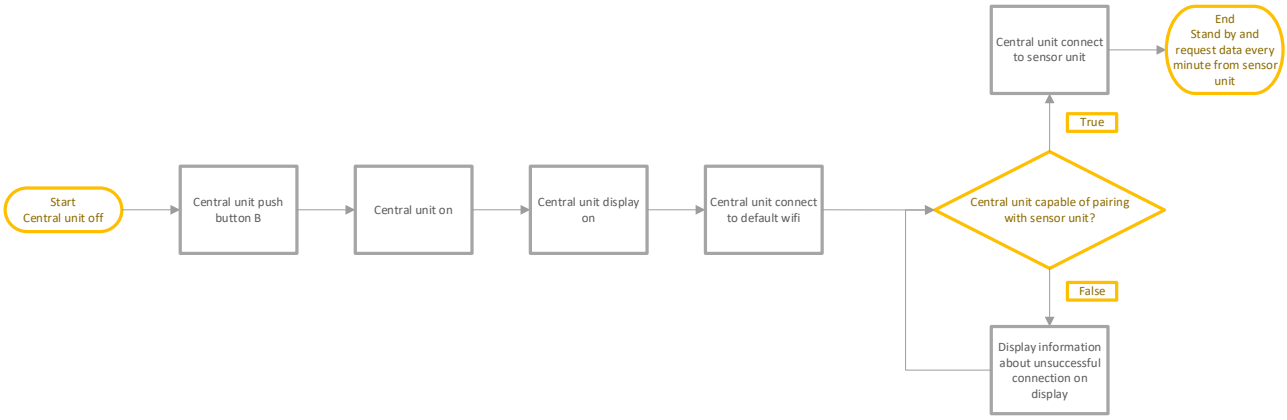

Figure 13: AP-NURSE Care event flow 2

Event flow test 3

Event flow test 3 verifies:

- turning off central unit
- unpairing due to the increase of distance between sensor unit and central unit
- turning sensor unit off
- resetting sensor unit

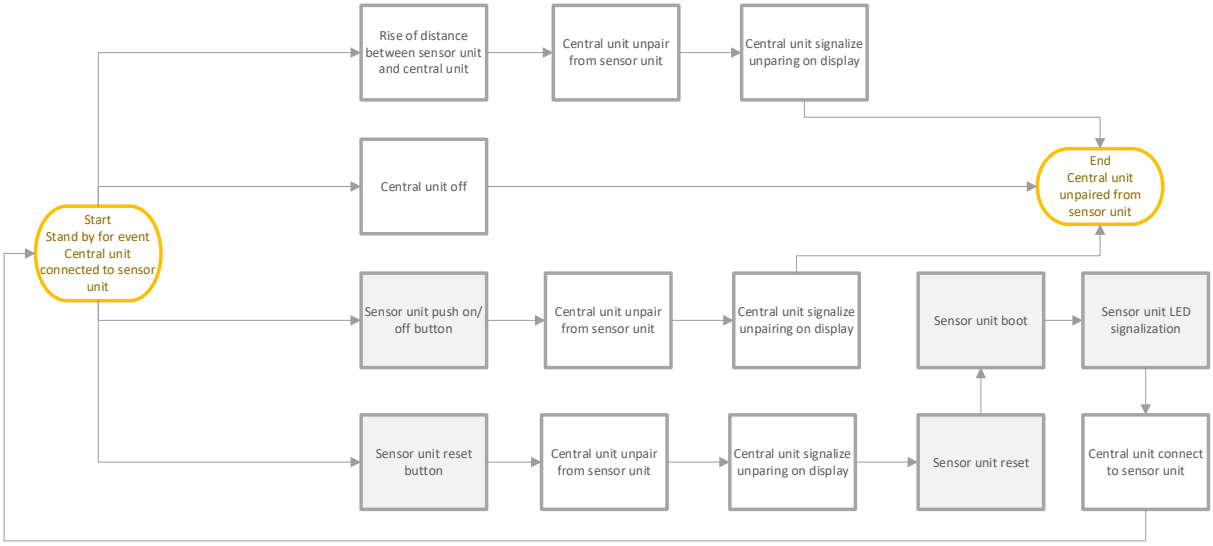

Figure 14: AP-NURSE Care event flow 3

Event flow test 4

Event flow test 4 verifies:

- manual wi-fi access point creation

Figure 15: AP-NURSE Care event flow 4

Event flow test 5

Event flow test 5 verifies:

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

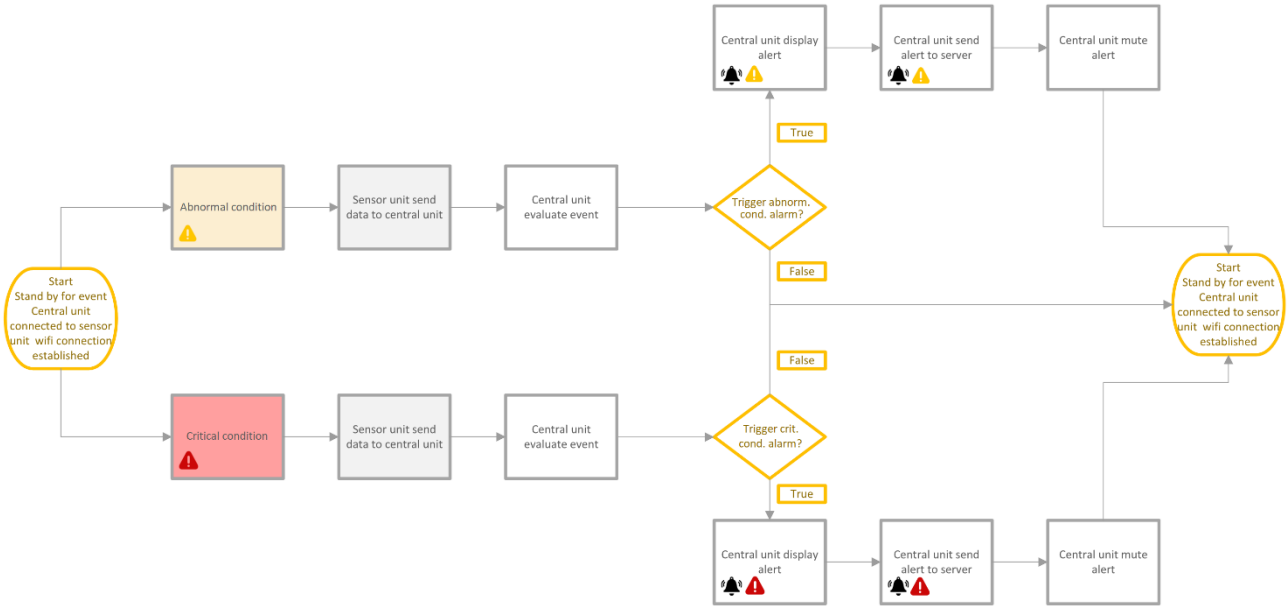

Figure 16: AP-NURSE Care event flow 5

Specialized tests and sensor tests - ST

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

- unpairing distance in case of clear distance between central unit and sensor unit
- unpairing distance in case of distance with barriers between central unit and sensor unit
- functionality of each sensor, triggering an abnormal condition and critical condition

Taking into account all event flow and sensor tests, 21 function test were defined for AP-NURSE Care M5stack devices. The final overview and description of function tests of for AP-NURSE Care - MSTACK devices can be found in Table 8.

Table 8: Overview and description of function tests of for AP-NURSE Care - M5stack devices

Test	Initial state	Event					End state	Event flow test number
EFT-M-1	sensor unit off, central unit off	sensor unit push on/off button	sensor unit on	sensor unit boot	sensor unit LED signalization		sensor unit stand by	1
EFT-M-2	sensor unit off, central unit off	central unit push button B	central unit on	central unit display on	central unit create access point		display information about unsuccessful connectionwith sensor board on display	2
EFT-M-3	sensor unit on, central unit off	central unit push button B	central unit on	central unit display on	central unit create access point	central unit connect to sensor unit	stand by and request data every minute from sensor unit	2
EFT-M-4	stand by for event central unit connected to sensor unit	rise of distance between sensor unit and central unit	central unit unpair from sensor unit	central unit signalize unparing on display			central unit unpaired from sensor unit	3
EFT-M-5	stand by for event central unit connected to sensor unit	central unit off					central unit unpaired from sensor unit	3
EFT-M-6	stand by for event central unit connected to sensor unit	sensor unit push on/off button	central unit unpair from sensor unit	central unit signalize unpairing on display			central unit unpaired from sensor unit	3
EFT-M-7	stand by for event central unit connected to sensor unit	sensor unit reset button	central unit signalize unpairing on display	sensor unit reset, Sensor unit boot	sensor unit LED signalization	central unit connect to sensor unit	stand by for event Central unit connected to sensor unit	3
EFT-M-8	stand by for event central unit connected to sensor unit no wifi connection	central unit push button A	central unit creates access point to wifi 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	successful wifi connection	4
EFT-M-9	stand by for event central unit connected to sensor unit	trigger abnormal condition	filter event				stand by for event Central unit connected to sensor unit	5
EFT-M-10	stand by for event central unit connected to sensor unit	trigger critical condition	don't filter event	signalize critical condition alarm on central unit display	central unit send alert to server	display alert in web browser, mute alert	stand by for event Central unit connected to sensor unit	5
EFT-M-11	stand by for event central unit connected to sensor unit	trigger abnormal condition	don't filter event	signalize abnormal condition alarm on central unit display	central unit send alert to server	display alert in web browser, mute alert	stand by for event Central unit connected to sensor unit	5
ST-M-1	stand by for event central unit connected to sensor unit	trigger temperature sensor unit					catch abnormal condition	ST
ST-M-2	stand by for event central unit connected to sensor unit	trigger humidity sensor unit					catch abnormal condition	ST
ST-M-3	stand by for event central unit connected to sensor unit	trigger movement sensor unit					catch abnormal condition	ST
ST-M-4	stand by for event central unit connected to sensor unit	trigger accelerometer sensor unit					catch abnormal condition	ST
ST-M-5	stand by for event central unit connected to sensor unit	trigger noise sensor unit					catch abnormal condition	ST
ST-M-6	stand by for event central unit connected to sensor unit	trigger light sensor unit					catch abnormal condition	ST
ST-M-7	stand by for event central unit connected to sensor unit	trigger gas sensor unit					catch critical condition	ST
ST-M-8	stand by for event central unit connected to sensor unit	trigger gas IR sensor unit					catch critical condition	ST
ST-M-9	sensor unit off, central unit off	20m distance between reciever and transmitter, **no barriers**	lower the distance between sensor unit and central unit	central unit pair			find out maximum distance for central unit to pair with sensor unit in case of no barlers between them	ST
ST-M-10	sensor unit off, central unit off	20m distance between reciever and transmitter, **with barriers**	lower the distance between sensor unit and central unit	central unit pair			find out maximum distance for central unit to pair with sensor unit in case of single or several walls between them	ST

3.2. 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 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 the specific application, individual alerts can be muted. For example: walking in the room during the daylight. However, in general, the system must detect all events and it's up to logic layer of device to choose whether to trigger an alert.

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 sensor boards are to be build for flexible addition or removal of sensors due to various reasons, such as: increased possibilities of detecting the error in the device functionality by easily removable sensors, changing the identified faulty sensors, future testing of alternative sensors and mostly the possibility changing the sensors itself without soldering, but only using screws and pre-manufactured cables for this purpose for each sensor.

3.2.1. AP-NURSE Home test cases

Since the versions of AP-NURSE Home were changed, so were the test cases. Each modified version has its own set of test cases, which were designed to be tested in the physical testing environment. The internal logic of sensor board 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 9. 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 9: Modified 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				✓					⚠

Explanatory notes on alert:

- permitted event, no alert 
- abnormal condition 
- critical condition 

3.2.2. AP-NURSE Care test cases

As in the case of the AP-NURSE Home version (sub-section 3.2.1) also the the AP-NURSE Care M5stack versions were modified. The changes in the test cases listed in Table 10 reflect the new requirements for the modified versions of AP-NURSE. Based on this procedure, the functionality and behaviour of the used sensor will be tested together with the overall functionality of all AP-NURSE versions. The test cases for the AP-NURSE Due to complications with the required drivers, the AP-NURSE Care test cases were not carried out so far, they will be included in Deliverable D.T2.2.5. The main difference between the test cases of AP-NURSE Home and Care are in case of the AP1-M version, where all tests requiring the light sensor were omitted. This exclusion of the “TV on” and “Lamp on” events were made due to the fact, that only 4 peripheries are possible to connect to the M5stack devices.

Table 10: Modified 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 !

3.3. Physical testing environment for test cases

Both systems, AP-NURSE Home and Care M5dstack, 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, the applicability of AP-NURSE in real environment and also not to bother the clients and the staff of care centres, a special testing room was designed and prepared at STU. For the success of the testing phase, it is very important to gain practical experience with all prototypes and to validate the prepared scenarios or test cases. Therefore, the testing has to 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 is carried out locally at STU. If cases occur, when the local testing is insufficient, the testing will continue 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)

The primary arrangement of the testing room is shown in Figure 17 - Figure 20.

Figure 17: Testing room - bed, armchair, open cabinet, small table

Figure 18: Testing room - tables, chairs, shelves, coffeemaker, phone

Figure 19: Testing room - washbasin, exit doors, chairs, coat hanger

Figure 20: Testing room - lockable cabinet, washbasin

3.4. Virtual testing environment

To program, build and flash the app into the AP-NURSE device, it is possible to use the Arduino IDE v 1.8.9 virtual testing environment. In order to use this environment for both AP-NURSE Home and Care M5stack, the following packages are required.

- https://www.arduino.cc/download_handler.php?f=/arduino-1.8.9-windows.exe (Windows)
- For AP-NURSE Home, the ESP8266 package is needed
- For AP-NURSE Care M5stack, the ESP32 / M5STICK-C is needed

In the following chapters the procedures for using the virtual testing environment will be presented, for both AP-NURSE Home and Care M5stack. Since the procedures are almost identical, the majority of examples is shown only for the AP-NURSE Home platform.

3.4.1. Install drivers

Each device communicates through serial port, which needs to be recognized and properly installed, depending on which operating system is running on the computer. If there is a problem with connectivity, there are probably driver issues in the system. Correct drivers for the devices are as follows:

- AP-NURSE Home – ESP8266 – CH340G driver - http://www.wch.cn/download/CH341SER_EXE.html
- AP-NURSE Care M5stack – M5STICK – CP2104 driver - https://m5stack.com/pages/download

3.4.2. Install dependencies

All steps required to install the depencies are presented in this chapter and are valid for both AP-NURSE Home and Care M5stack platforms. However, the AP-NURSE Care M5stack platform requires additional dependencies to be installed, shown in Figure 21. These dependencies are the following ones:

- Adafruit BME680 Library and Adafruit Unified Sensor Libraries by Adafruit
- VL53L0X Library by Pololu
- M5StickC Library by M5StickC

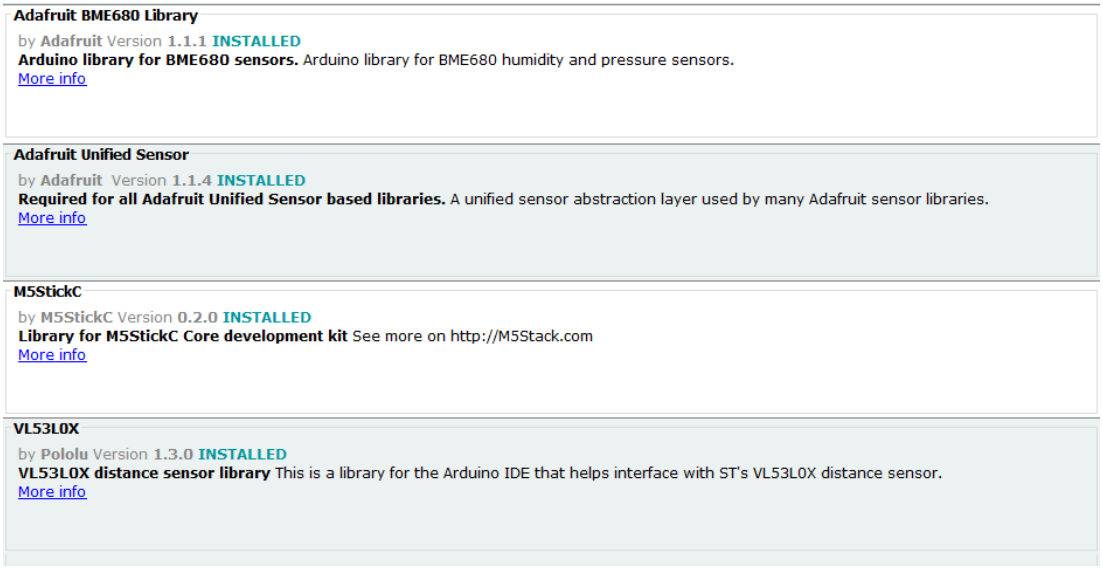

Figure 21: AP-NURSE Care M5stack libraries in Arduino IDE

1. Open Arduino Library Manager

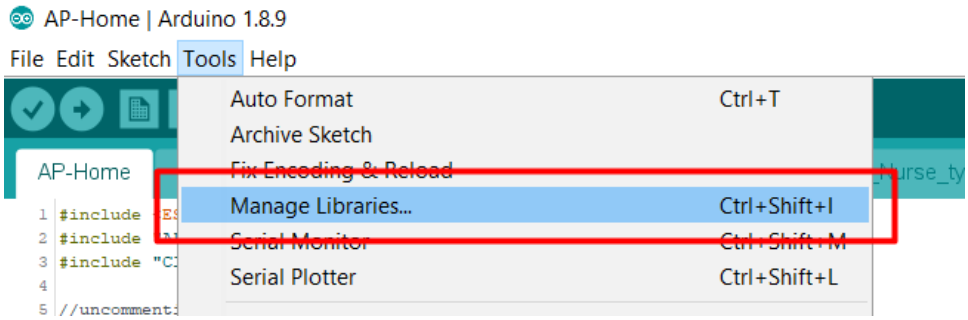

Figure 22: Managing libraries in Arduino IDE

2. Install the Adafruit BME280 Library and Adafruit Unified Sensor libraries

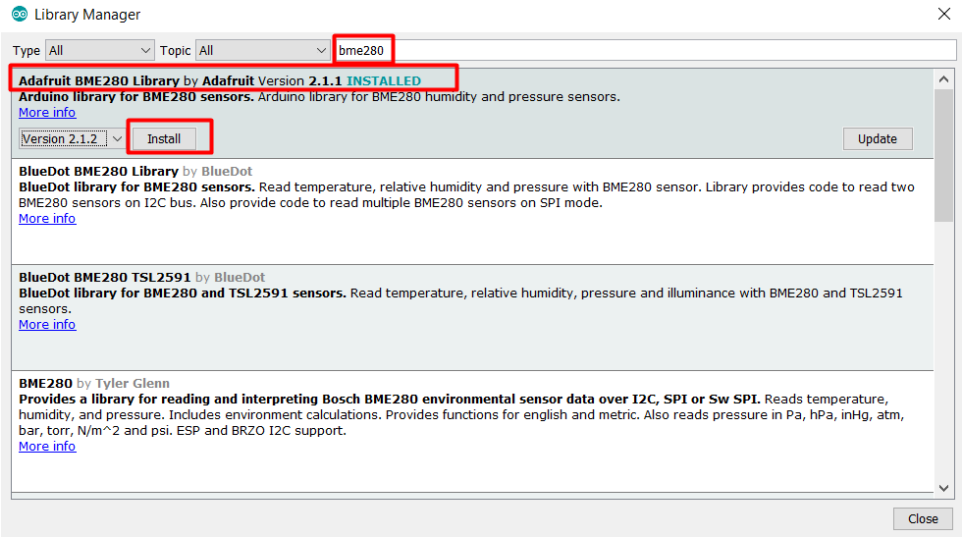

Figure 23: Selecting appropriate libraries in Arduino IDE

3.4.3. Programming

All source files required for building the codes were managed on GitHub [github.com/vtothsvk/AP-Home],which is described in chapter 3.5. To program the app, open the Arduino core project AP-Home.ino Sensor control (Enable/Disable), handled by the _ENABLE directives in Sensor_enable.h. The code example is shown below:

```
/** Sensor enable directives
 *
 *  @note uncommenting any of the following results in disabling respective sensor reading
 */
#define _PIR_ENABLE
```

Sensor threshold configuration is handled by the _TH directives in AP-Home.ino. The code example is shown below:

```
/** Threshold directives
 *
 *  @note each level represents one 255th of the reference voltage (eg. a threshold of 100 @ 3.3V represents 1.29V)
 */
#define NOISE_TH        255
#define SMOKE_TH        255
#define GAS_TH          60
#define LIGHT_TH        80
#define PRESSURE_TH     80
#define TEMP_TH         255
```

3.4.4. Building

1. The ESP8266 MCU has to be set as the active build target:

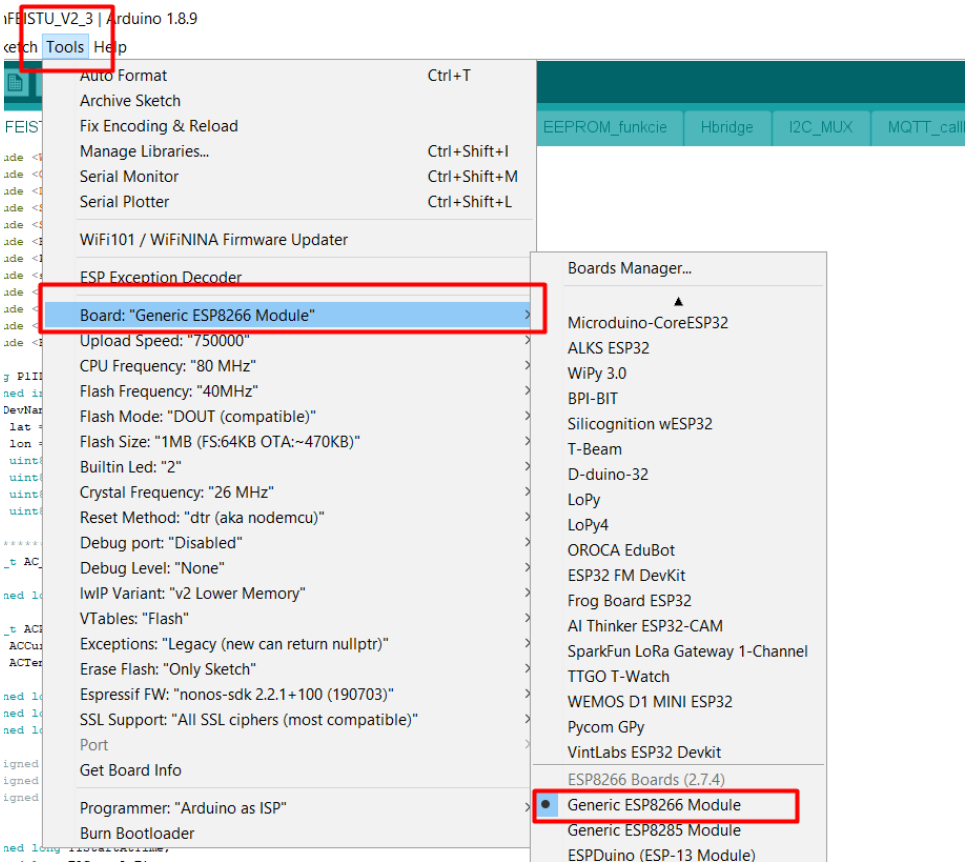

Figure 24: Selecting appropriate active build target in Arduino IDE

2. The NodeMCU devboard serial port has to be selected:

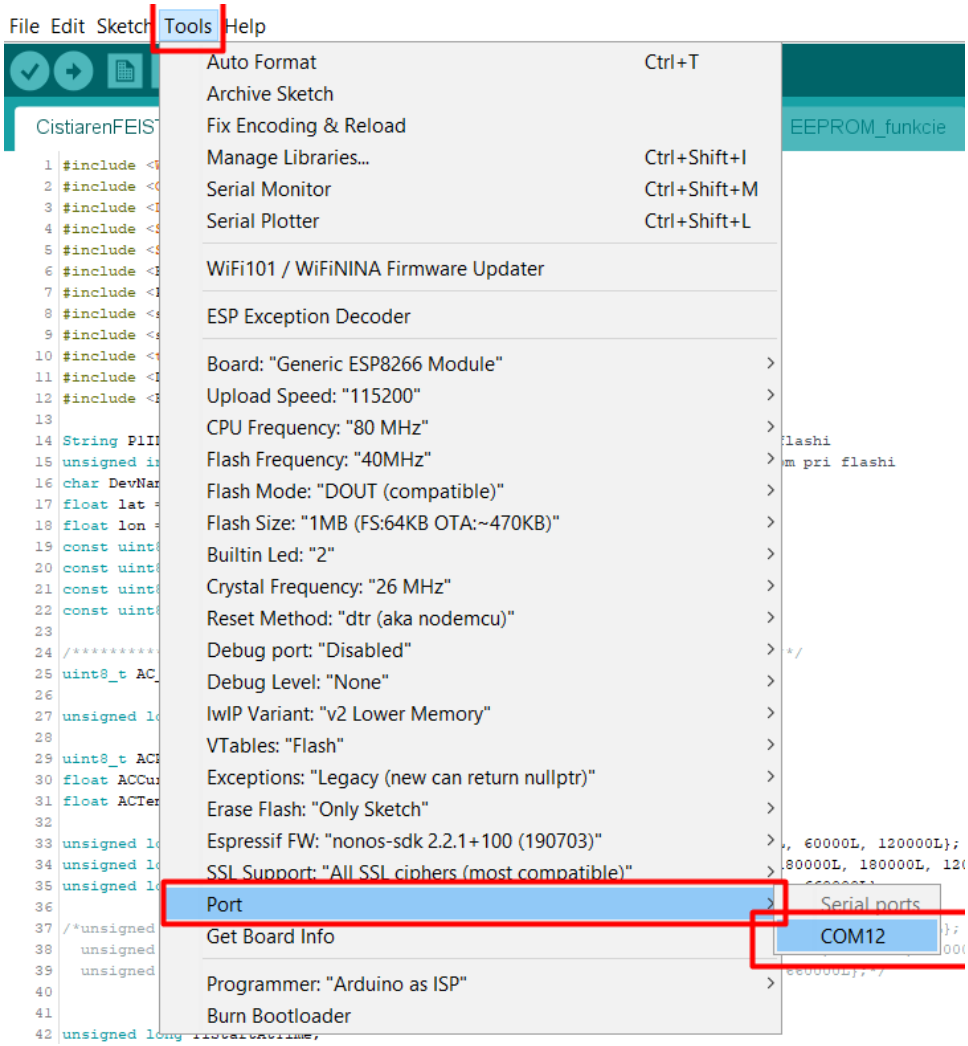

Figure 25: Selecting appropriate serial port (specific number may vary)

3. Building (compiling and linking into a .elf image)
4. Flashing

3.4.5. Debugging

1. The debugging of the AP-NURSE Home units is handled via the UART bus connected to the ESP8266 NodeMCU devboard through USB port.
2. When plugged in to the computer, the board Serial port should be connected using one of the possible serial monitor terminals (e.g. HTerm, TeraTerm or the Arduino IDE Serial Monitor):

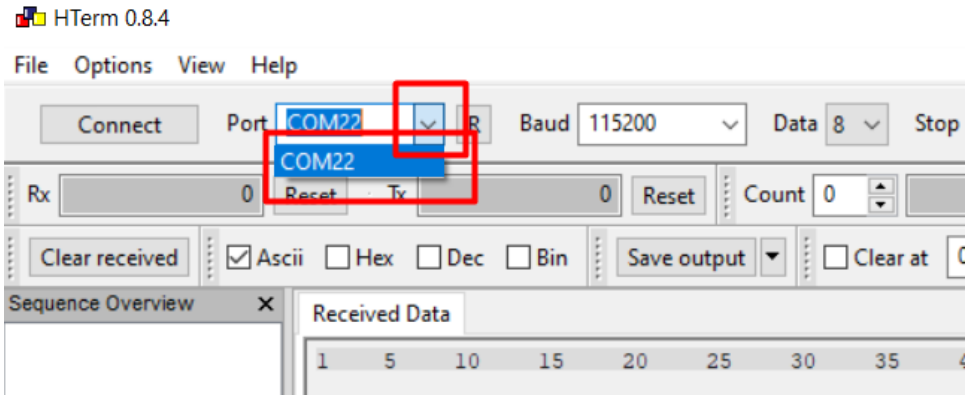

Figure 26: Connecting to appropriate serial port (specific number may vary)

3. Select a 115200 bit/s baud rate and new line at new line character (\n or LF):

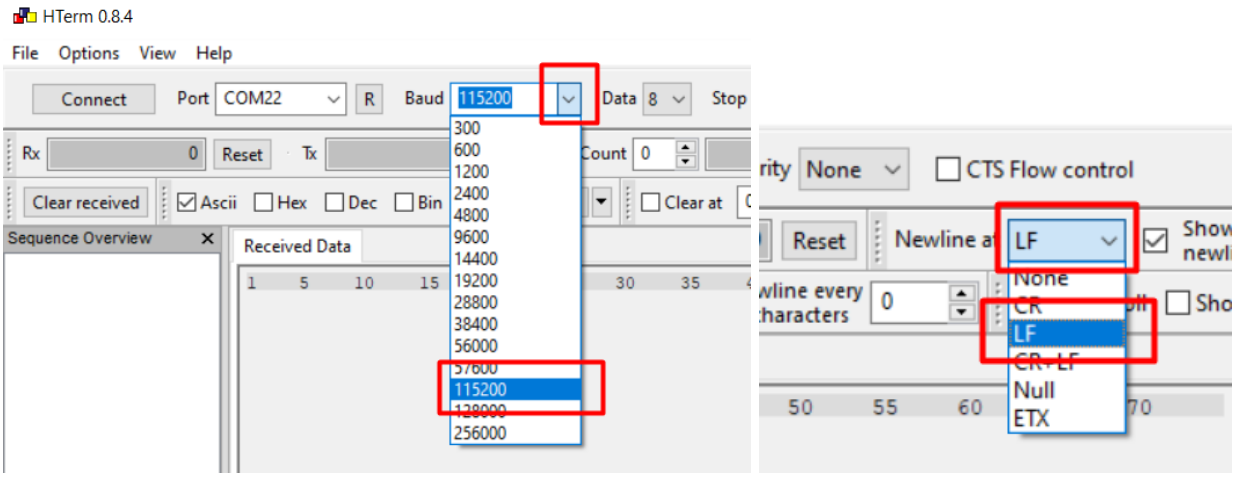

Figure 27: Selecting appropriate Baud rate and new line character

4. Connect to board:

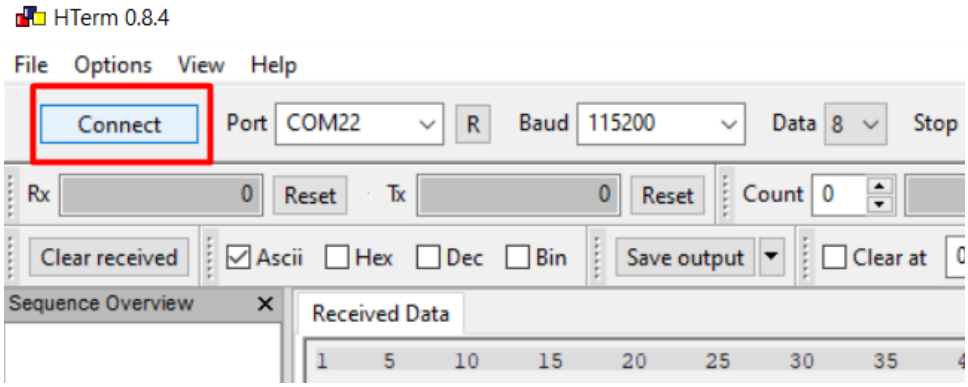

Figure 28: Connecting to the board

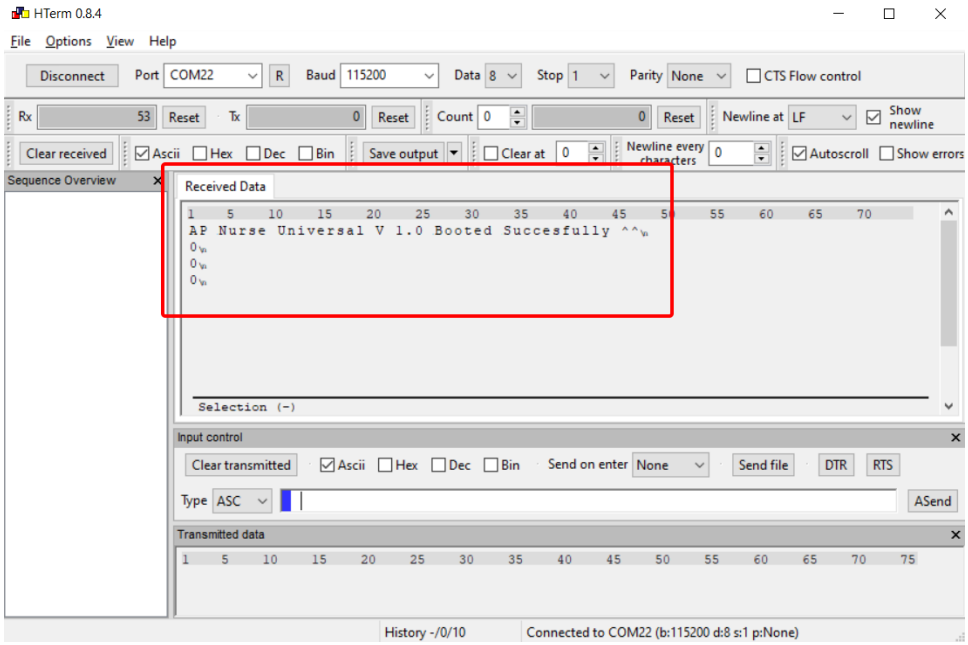

Figure 29: Received data if board connected successfully

The AP-NURSE Home unit periodically updates the sensor data and prints out the status code. Individual status codes with their respective meaning are listed in the ap_alert enumeration in AP_Nurse_types.h. The code example is shown below:

```
/** AP-NURSE Alert type
 *
 *  @note each alert uses a dedicated bit of the status code allowing multiple
simultanious alert triggers
 */
#ifndef ap_alert_type
#define ap_alert_type
```

```
typedef enum ap_alert{
    STATUS_OK = 0,
    MOTION_ALERT = 1,        //0b00000001
    NOISE_ALERT = 2,         //0b00000010
    SMOKE_ALERT = 4,         //0b00000100
    GAS_ALERT = 8,           //0b00001000
    LIGHT_ALERT = 16,        //0b00010000
    PRESSURE_ALERT = 32,     //0b00100000
    GENERAL_ALERT = -1000,
    I2C_NO_DATA = -1001
}status_t;
#endif
```

3.5. Workflow & bug reporting

All communication about testing and bug reporting was realized through GitHub platform, as visualized on following Figure:

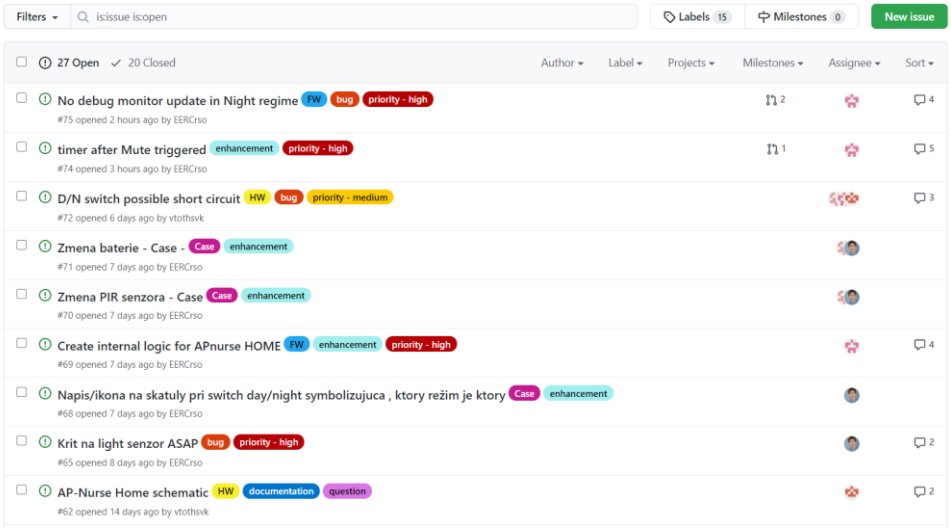

Figure 30: GitHub project issues reporting

Every issue is labelled with according label or priority marker. Workflow for each issue is tracked and the time frame is clearly visible also. Moreover, github issues is organised into projects. These projects are managed by a variety of project management methods (for example Kanban).

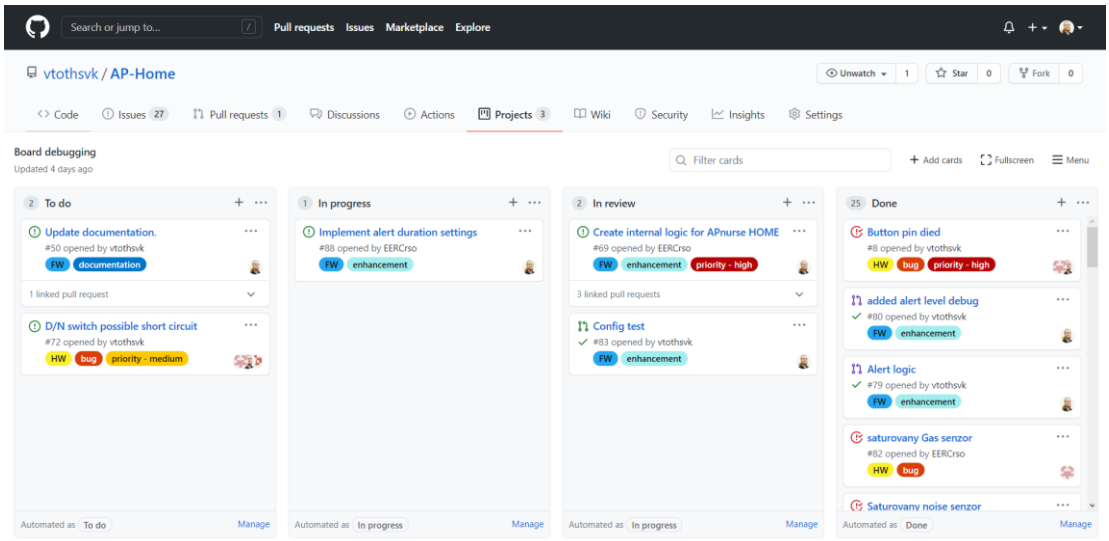

Figure 31: Kanban board of the “Board debugging” project

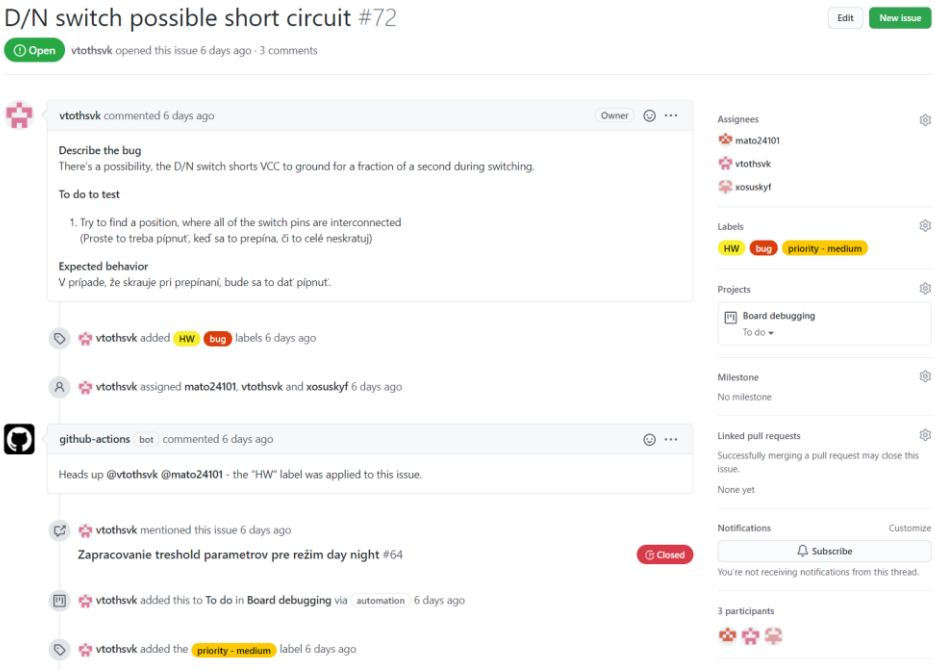

Figure 32: Open issue in Github

After the problem is resolved successfully, the issue is closed. For purposes of this project this functionality was sufficient, however the complete functionality of this GitHub feature is more complex (https://guides.github.com/features/issues/).

4. Testing results

4.1. AP-NURSE Home

4.1.1. Results of function tests

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 11 - Table 14 are the test protocols that were carried out as a result of all function tests for all proposed versions of the AP-NURSE Home device. Even though the function tests were carried oud for the initial AP versions, they are also valid for the new versions of AP-NURSE Home, therefore in the following tables, the new AP version IDs are listed. It should be noted, that the original AP3 and AP5 versions were also tested, but are not included in this report. The testing protocol of the new AP7-H is also omitted, since this version uses the same configuration of sensors as AP1-H, however is placed in a different location.

Table 11: Function test protocol for AP-NURSE Home - AP1-H

Device:	AP1-H	Date:	3.12.2020
Test site:	Slovak Technical University 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 bracelet board 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	
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	

Device:	AP1-H	Date:	3.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology Institute of Power and Applied Electrical Engineering	Name:	Jozef Bendík
TESTS			
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 12: Function test protocol for AP-NURSE HOME - AP2-H

Device:	AP2-H	Date:	3.12.2020
Test site:	Slovak Technical University 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 the bracelet board 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	
ST-H-2	~	Not included in this AP version	
ST-H-3	☑		
ST-H-4	~	Not included in this AP version	

Device:	AP2-H	Date:	3.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology Institute of Power and Applied Electrical Engineering	Name:	Jozef Bendík
TESTS			
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 13: Function test protocol for AP-NURSE HOME - AP4-H

Device:	AP4-H	Date:	3.12.2020
Test site:	Slovak Technical University 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 bracelet board 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	
ST-H-2	~	Not included in this AP version	
ST-H-3	☑		

Device:	AP4-H	Date:	3.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology Institute of Power and Applied Electrical Engineering	Name:	Jozef Bendík
TESTS			
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 14: Function test protocol for AP-NURSE HOME - AP6-H

Device:	AP6-H	Date:	3.12.2020
Test site:	Slovak Technical University 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 bracelet board 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	
ST-H-2	~	Not included in this AP version	
ST-H-3	☑		

Device:	AP6-H	Date:	3.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology Institute of Power and Applied Electrical Engineering	Name:	Jozef Bendík
TESTS			
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.

4.1.1.1. Conclusion of the AP-NURSE Home function tests

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. In the future, if noise sensor is required, a different type of noise sensor will have to be used. The new versions of AP-NURSE Home introduced in chapter 2 do not include the noise sensor. It was only used for testing purposes to justify the modifications of AP-NURSE Home versions.

4.1.2. Sensor sensibility tests

Each sensor on sensor board 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.

4.1.2.1. PIR (movement) sensor

As it was explained in chapter 2, the original PIR sensor was replaced by a new one, due to its overall better performance and smaller size. The sensibility of the new PIR sensor was tested on various distances and angles. Multiple measurements were made for each angle of sensor. The results are shown in Table 15.

Table 15: 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 every time. 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.

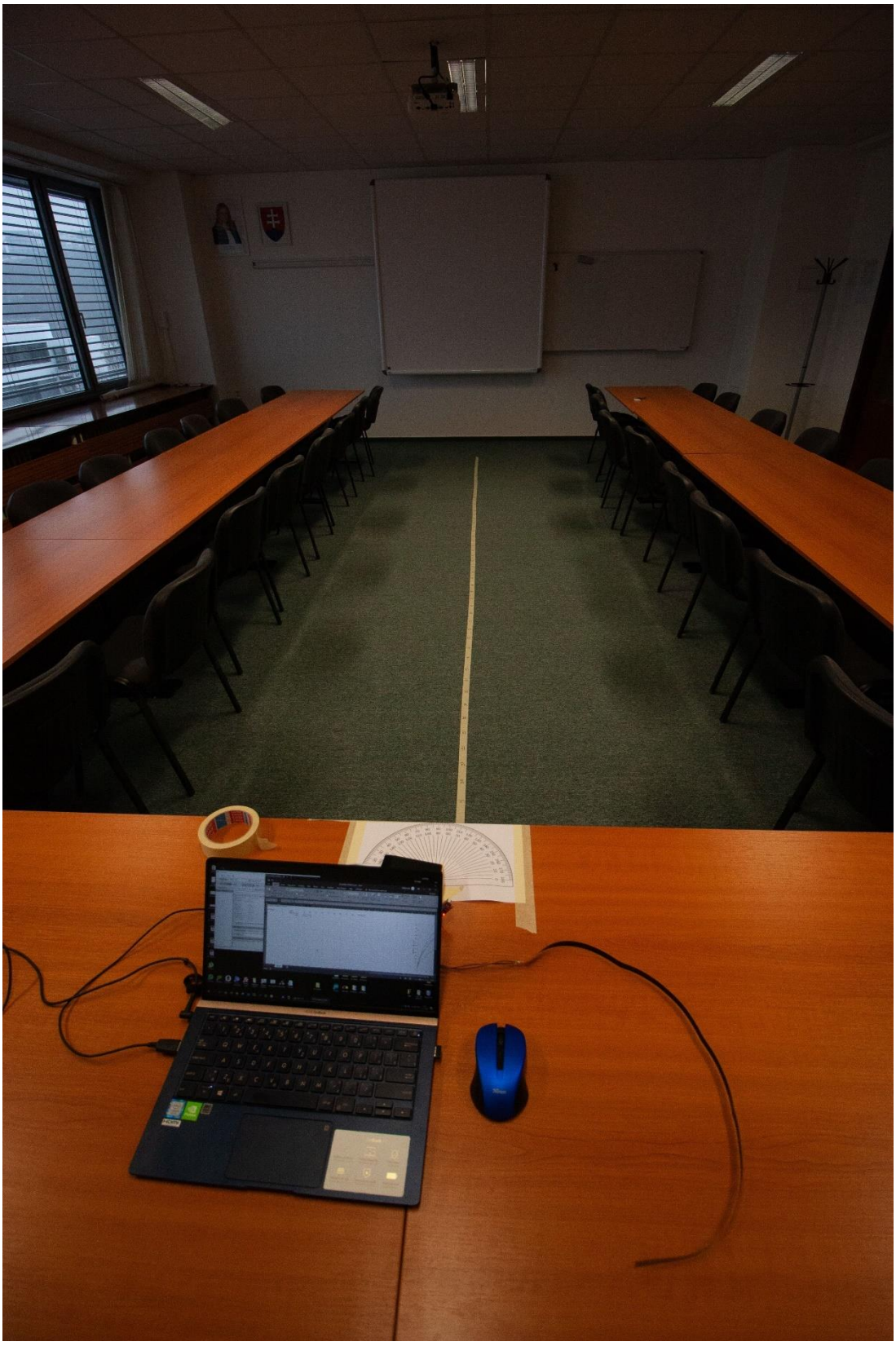

Figure 33: Setup for experimental measuring of PIR sensor sensibility

4.1.2.2. 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.

4.1.2.3. 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 5 light sources were measured:

- Incandescent lightbulb
- LED
- Compact fluorescent lamp (CFL)
- LCD display (TV / PC / notebook alternative)
- Cloudy weather – direct sunlight – placement in window

The results for each source are shown in Figure 34.

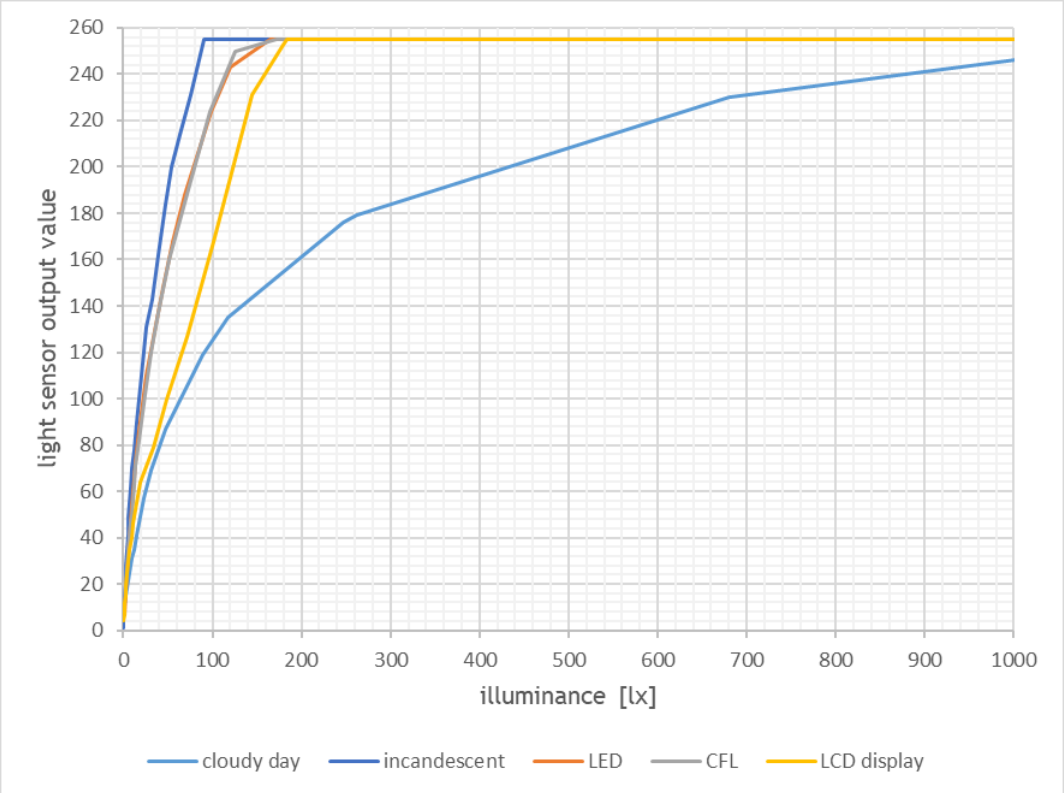

Figure 34: Measured illuminance against light sensor output value

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 sensor board.

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.

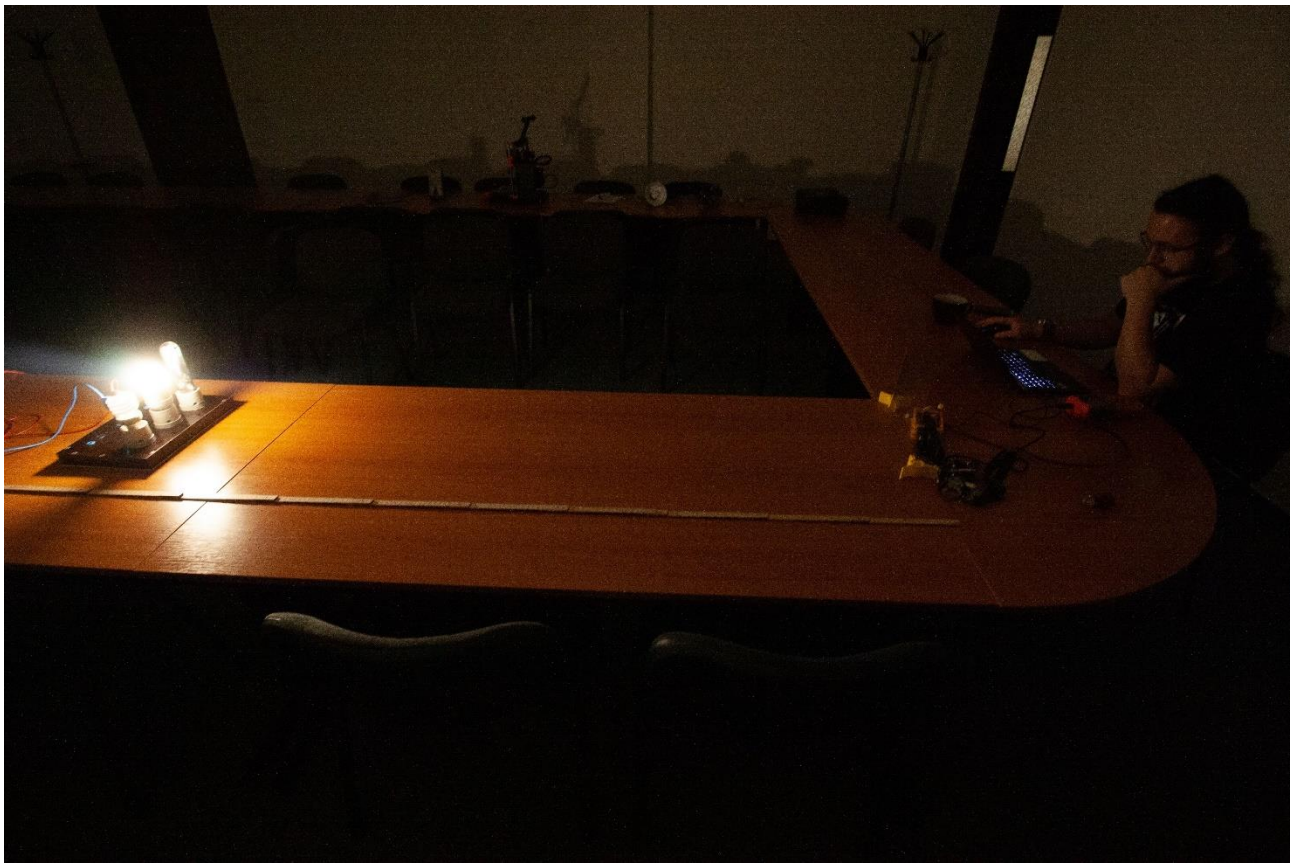

Figure 35: Experimental measuring the light sensor output

4.1.2.4. 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).

4.1.2.5. 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.

4.1.3. Test cases

The test cases were carried out in accordance with Table 9 in chapter 3.2.1. The protocols shown in Table 16 - Table 20 represent the results from the actual testing in the testing environment, which is described in section 3.3. The testing procedure is illustrated in Figure 36 and Figure 37.

Figure 36: Testing of AP1-H, test case 1

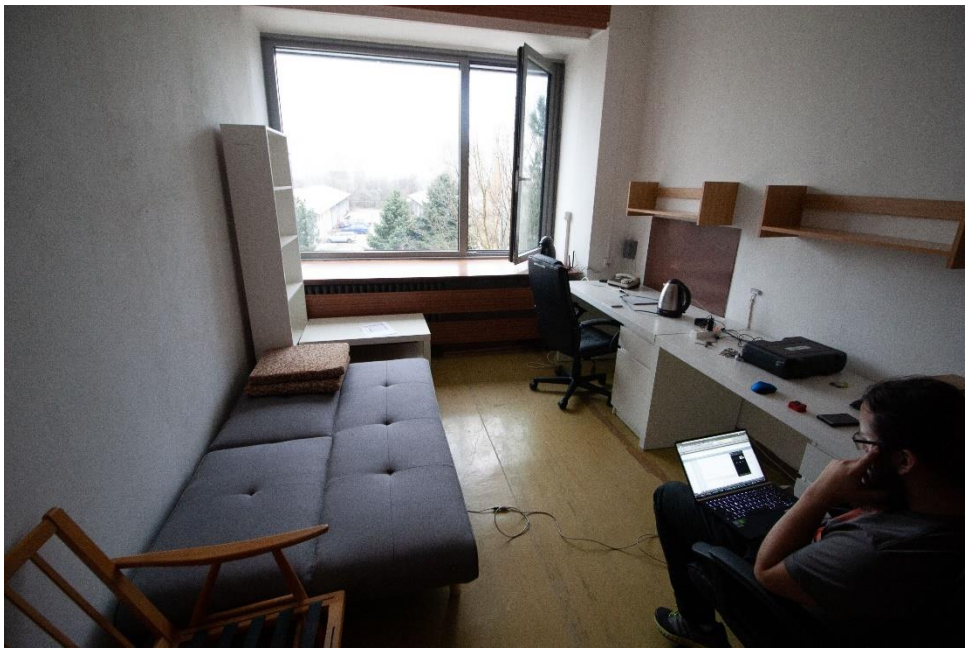

Figure 37: Testing of AP1-H, test case 9

Table 16: Test cases protocol for AP-NURSE Home AP1-H version

Device:	AP1-H	Date:	10.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology 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.	

Device:	AP1-H	Date:	10.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology Institute of Nuclear and Physical Engineering	Name:	Matej Cenký
Test case			
8	☒	The light sensor cannot detect small deviations from illuminance in the room as TV or lamp.	
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 17: Test cases protocol for AP-NURSE Home AP7-H

Device:	AP7-H	Date:	10.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology 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.	
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.	

Device:	AP7-H	Date:	10.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology Institute of Nuclear and Physical Engineering	Name:	Matej Cenký
Test case			
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.

Table 18: Test cases protocol for AP-NURSE Home AP2-H

Device:	AP2-H	Date:	10.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology 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/A	The internal logic for evaluating the time constants is not yet implemented, it will be tested in the near future.	
25	N/A		
26	N/A	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	N/A		
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 19: Test cases protocol for AP-NURSE Home AP4-H

Device:	AP4-H	Date:	10.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology 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 20: Test cases protocol for AP-NURSE Home AP6-H

Device:	AP6-H	Date:	10.12.2020
Test site:	Slovak Technical University Faculty of Electrical Engineering and Information Technology 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.

Additional test - Multi-node configuration

So far, all tests have been carried out for a single sensor board and a single bracelet board. However, situations in which several sensor boards need to be connected into a single bracelet 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.

4.1.3.1. Conclusion of AP-NURSE Home test cases

It was found out, that all tests were strongly dependent on the location of the sensor board 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
- **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 21.

Table 21: 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	N	N	N	N	N	N	N	N	N	N
Smoke	20	20	20	20	N	N	N	N	20	20
Gas	130	130	130	130	N	N	N	N	130	130
Light	F		F		N	N	N	N	F	
Pressure	N	70	N	N	N	N	N	N	N	N
Temp	1 °C / 3 min	1 °C / 3 min	1 °C / 3 min	1 °C / 3 min	N	N	N	N	1 °C / 3 min	1 °C / 3 min
Humidity	N	N	N	N	N	N	N	N	N	N
sensor states										
PIR	X		X							
NOISE	X	X	X	X	X	X	X	X	X	X

BME					X	X	X	X		
Extender					X	X	X	X		
Timers										
Mute	not implemented yet									
Holding abnormal conditions										
Holding critical conditions										
Stuck timer delay										

Explanatory notes:

- F – disables
- N – inactive
- X – sensor not included

4.2. AP-NURSE Care – M5STACK

AP-NURSE Care is based on the M5STACK platform. The system, hovewer, could not have been tested as of now, due to incompativle drivers of the testing teams computers. Specifically the CP210x USB to UART Bridge VCP Drivers, needed to establish communication with the M5Stack development modules. Unfortunately the drivers provided by the manufacturers did not seem to be compatible with the latest revision of the M5Stack modules and attemts to establish connection with alternative drivers were to no avail. This is not acceptable for device debugging and setting up in the real environment and therefore none of the AP-NURSE Care devices were tested. The workaround and step-by-step manual how to avoid this issue is in the creation and after its completion, it will be tested in the same manner as the AP-NURSE Home device versions. The solution to this problem is the implementation of OTA (over the air) firmware upgrade, 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 38 and Figure 39.

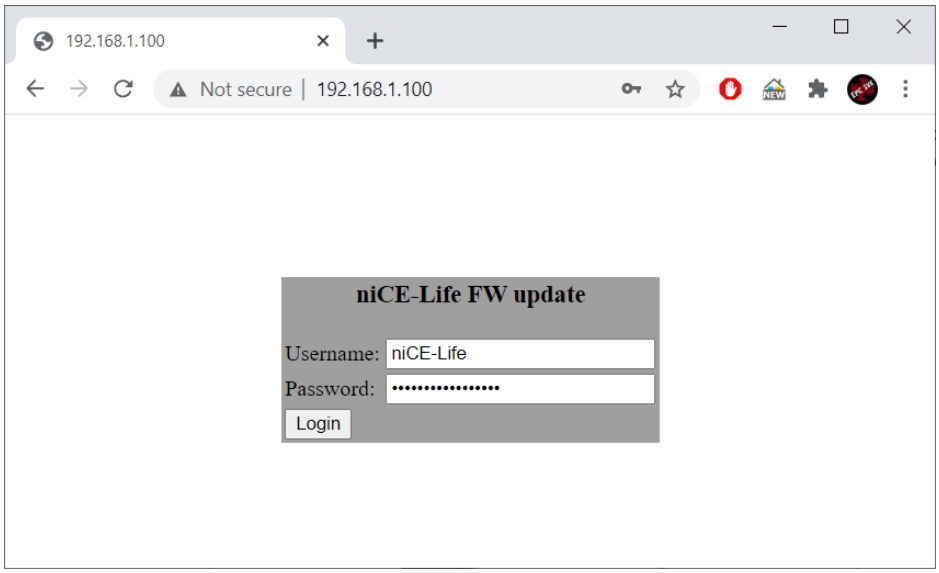

Figure 38 – OTA FW upgrade webserver login screen

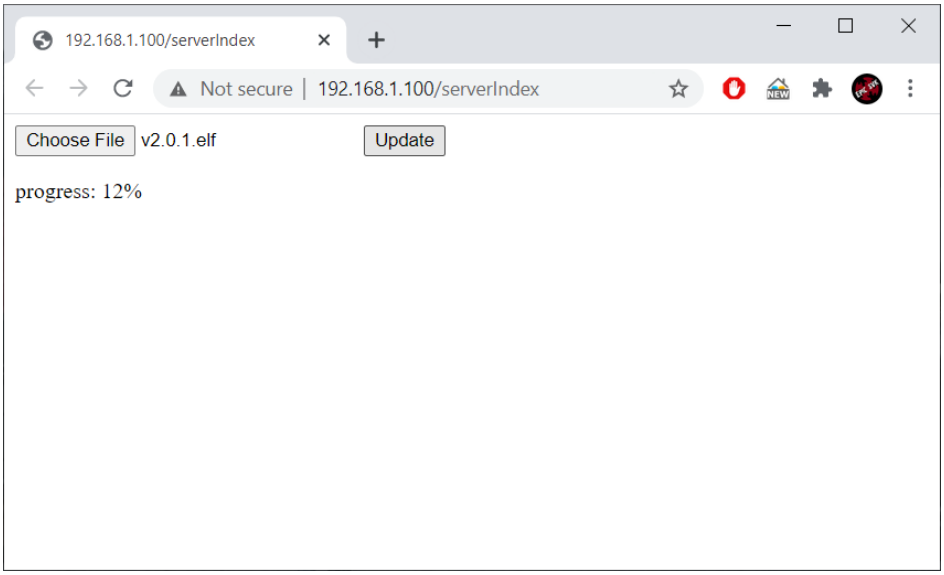

Figure 39 – OTA FW upgrade in progress

4.3. AP-NURSE Care - Waspmote

Due to the delay of the procurements of Waspmote components, the testing procedure, as defined in chapter 3, cannot 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 40**).
   b. Certification configuration on the Waspmote board side was tested, where the self signed certificate was in appropriate format exported from the Meshlium itself.
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.

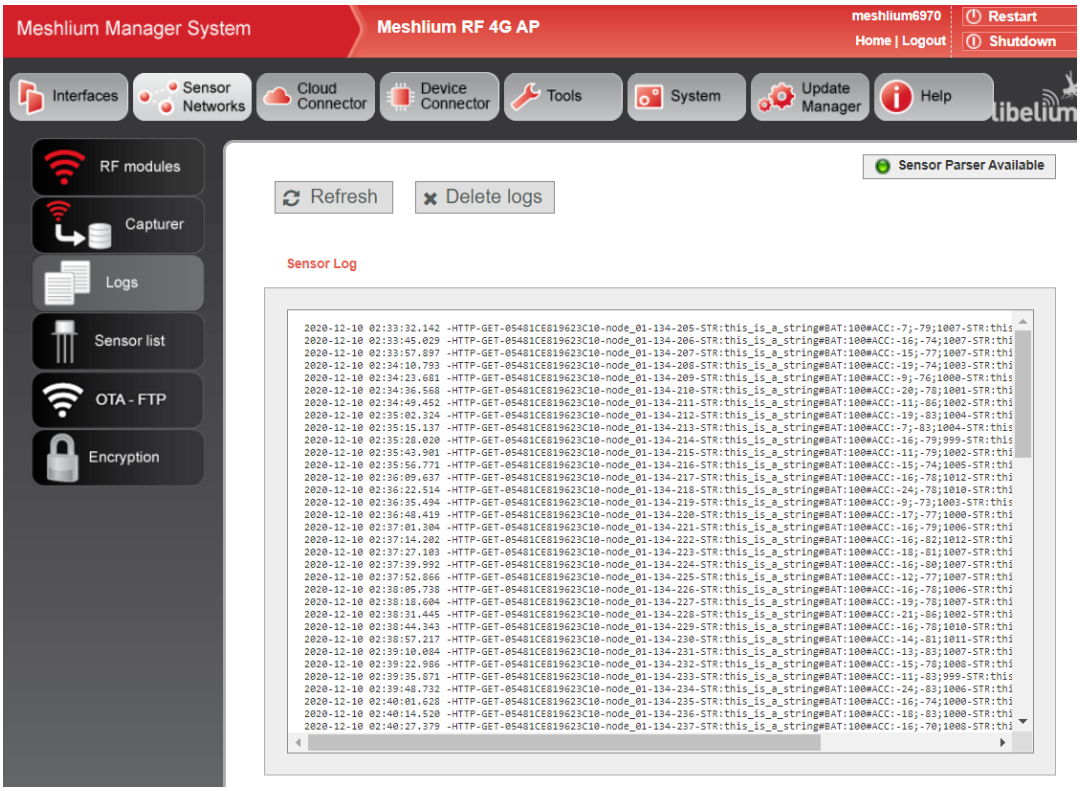

Figure 40: Meshlium HTTPS request logger

4.4. Software interface – data collection

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.

Moreover 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 are shown in Figure 41 and Figure 42.

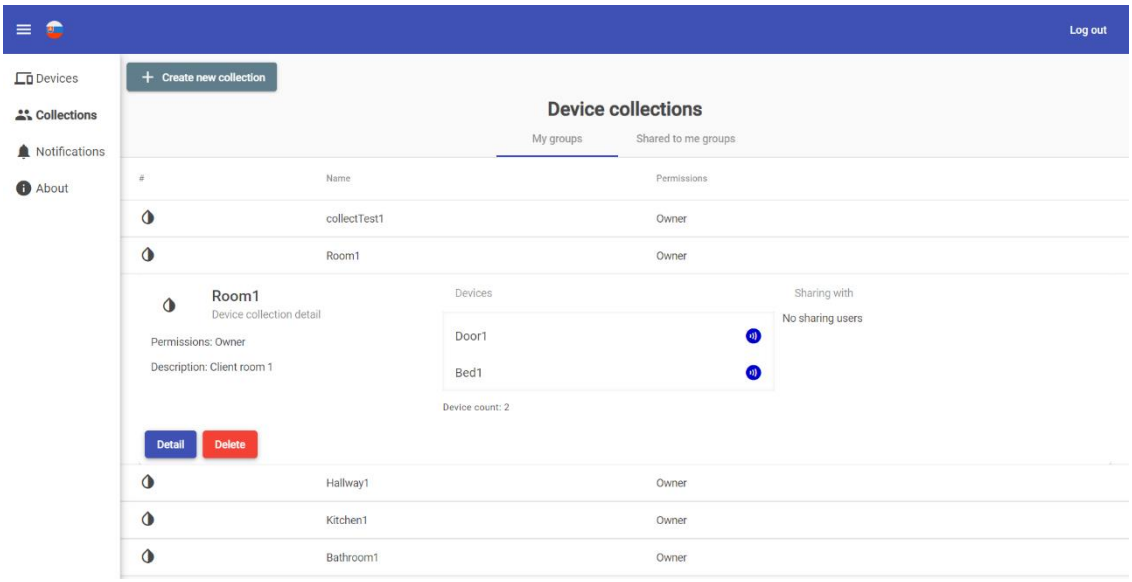

Figure 41 – Device collections tab

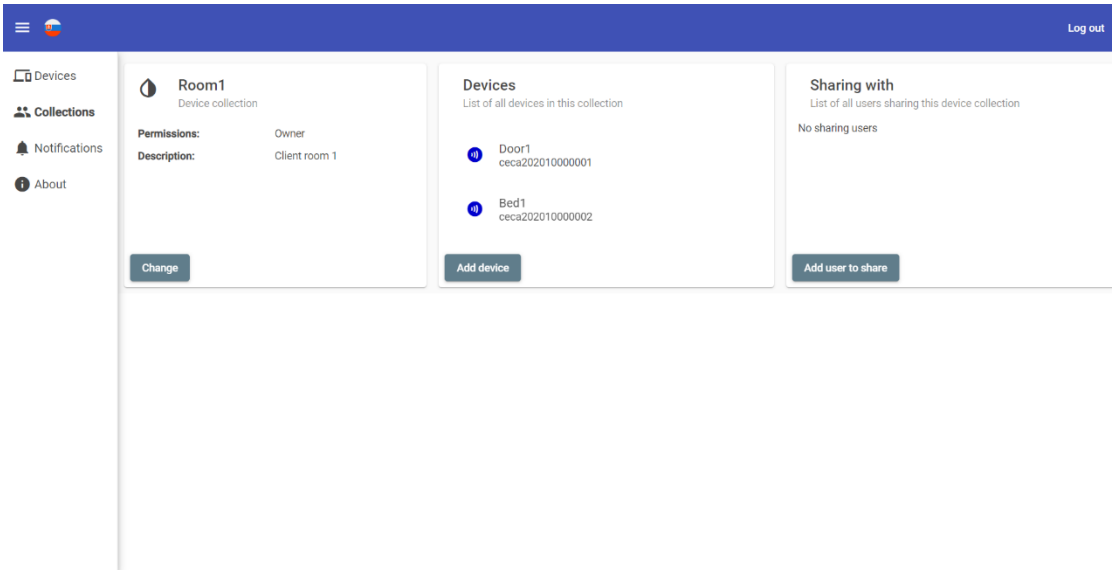

Figure 42 – Example of a device collection

Moreover data chart view customisation otpions were added, allowing the user to sroll and drag the chart and customise time interval to be displayed. Examples of daa preview are shown in Figure 43 and Figure 44.

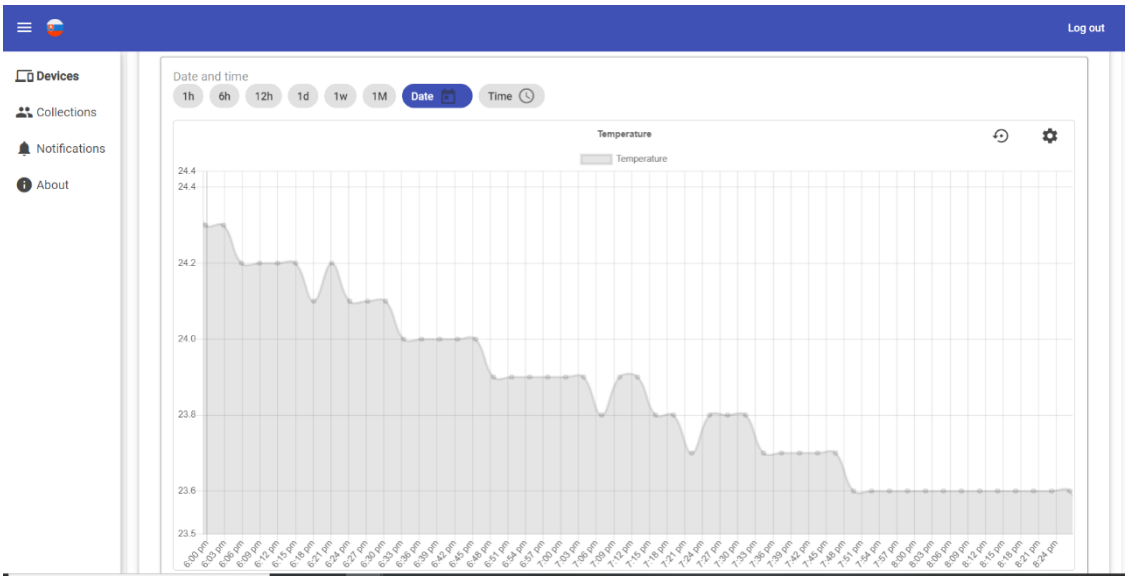

Figure 43 – IS data preview - Temperature

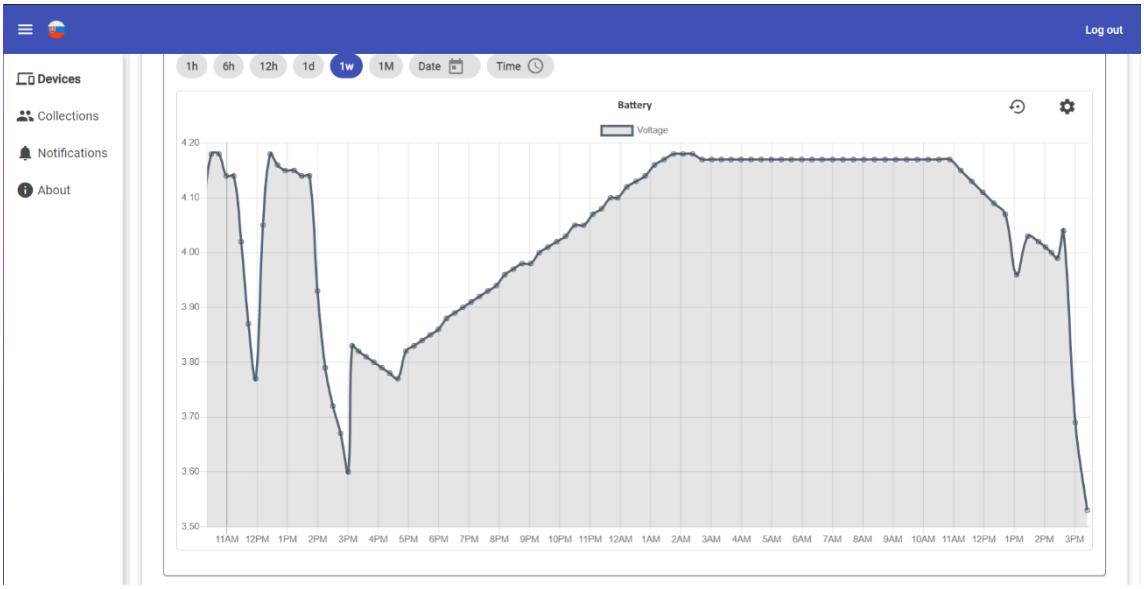

Figure 44 - IS data preview – Device battery voltage

5. Conclusion

This report summarizes the findings from the integral laboratory testing of the AP-NURSE technology. It consists of the description of changes against the previous design, definition of new AP-NURSE Home & Care versions, modification of the testing procedure and summarises the achieved results. The versions of AP-NURSE, selected based on specific needs of potential users in D.T2.2.3 [2], encompassed 6 versions (AP1-AP6) in case of AP-NURSE Home and 4 versions (AP1, AP2, AP4 and AP6) in case of AP-NURSE Care. Although the selection of these versions played an important part in the design of AP-NURSE devices, the testing phase had identified several issues that resulted in the modifications of original AP-NURSE versions. Among

the original versions AP3 and AP5 were cancelled and new versions were defined separately for AP-NURSE Home (AP1-H, AP2-H, AP4-H, AP6-H and AP7-H) and Care (AP1-M, AP2-M, AP4-M and AP6-M).

Based on the modifications of AP-NURSE versions, the testing methodology was modified. It should be noted, that the AP-NURSE Care M5stack platform was not tested because of the technical issues connected with the M5STICK devices working under Windows 10 operating system. This issue is taken care of and the devices will be tested in the near future in the same manner as the AP-NURSE Home devices. The same applies for the AP-NURSE Care Waspmote platform, since due to the delay in the procurement of technical components, the testing could not take place in time. This document however thoroughly describes the testing of the AP-NURSE Home platform. The tests include function tests, sensor sensitivity tests as well as test cases.

For each AP-NURSE Home version 24 function tests were defined, however in case of the four versions, several tests were 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. In case of the tests, which were carried out, the results were evaluated as expected results and unexpected results. The following results were achieved for the four AP versions:

- AP1-H – 20 expected results, 0 unexpected results, 4 exlcuded
- AP2-H - 18 expected results, 1 unexpected results, 5 exlcuded
- AP4-H - 16 expected results, 1 unexpected results, 7 exlcuded
- AP6-H - 19 expected results, 1 unexpected results, 4 exlcuded

The function tests identified very good performance of the AP-NURSE Home devices. As it can be seen from the results, their average success ratio was 96% and only 3 unexpected results were achieved, each caused by the low sensitivity of the noise sensor in case of the ST-H-5 sensor test.

The 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 is not usefull 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 sensored 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 (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.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.

For each AP-NURSE Home version several test cases were defined and performed. The tests were evaluated as passed, failed and limited, while the keyword limited represents a case, where under specific circumtances the test might be succesfull. The following results were achieved for the four AP versions:

- AP1-H – 4 passed, 5 failed, 2 limited
- AP2-H – 2 passed, 0 failed, 0 limited, 4 excluded (lacks implementation of software features)
- AP4-H – 4 passed, 0 failed, 0 limited
- AP6-H – 2 passed, 0 failed, 2 limited
- AP7-H – 6 passed, 2 failed, 2 limited

The results showed that the highest success rate was achieved in case of AP4-H and AP2-H and the lowest in case of AP1-H. However, it should be noted, that in case of AP2-H 2 test had to be excluded, since the evaluation logic had not been implemented in the AP-NURSE Home devices. The average total success rate (including also limited tests) is 87% and the total true success rate is (excluding limited tests) is 69 %. Fails in the test were in the majority of the cases caused by the humidity sensor, which was not capable of detectiong water boiling in electric keetle, the light sensor, which failed to detect TV and the gas sensor, wich was placed in a large distance from the possible source of smoke.

In general, it should be concluded that the test cases showed usefull 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.

In addition to testing, several version of the AP-NURSE Home and Care casing were designed. The design of the AP-NURSE Home testing consists of 3 parts, the testing for the device itself, for the wearables and the battery holder. Testing of the casing will be performed on-site, 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 tesiting stage will be documented in the next deliverables.

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