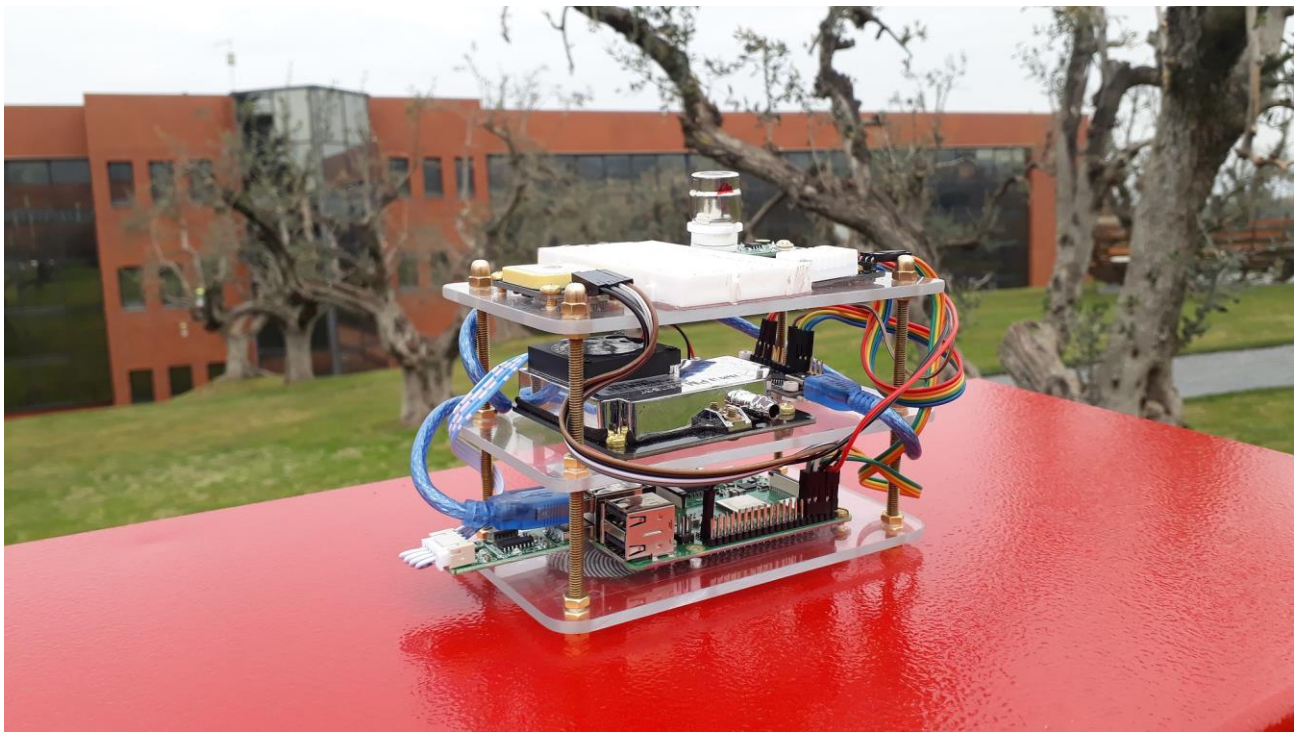
LPS AIR QUALITY STATION: QUICK START GUIDE



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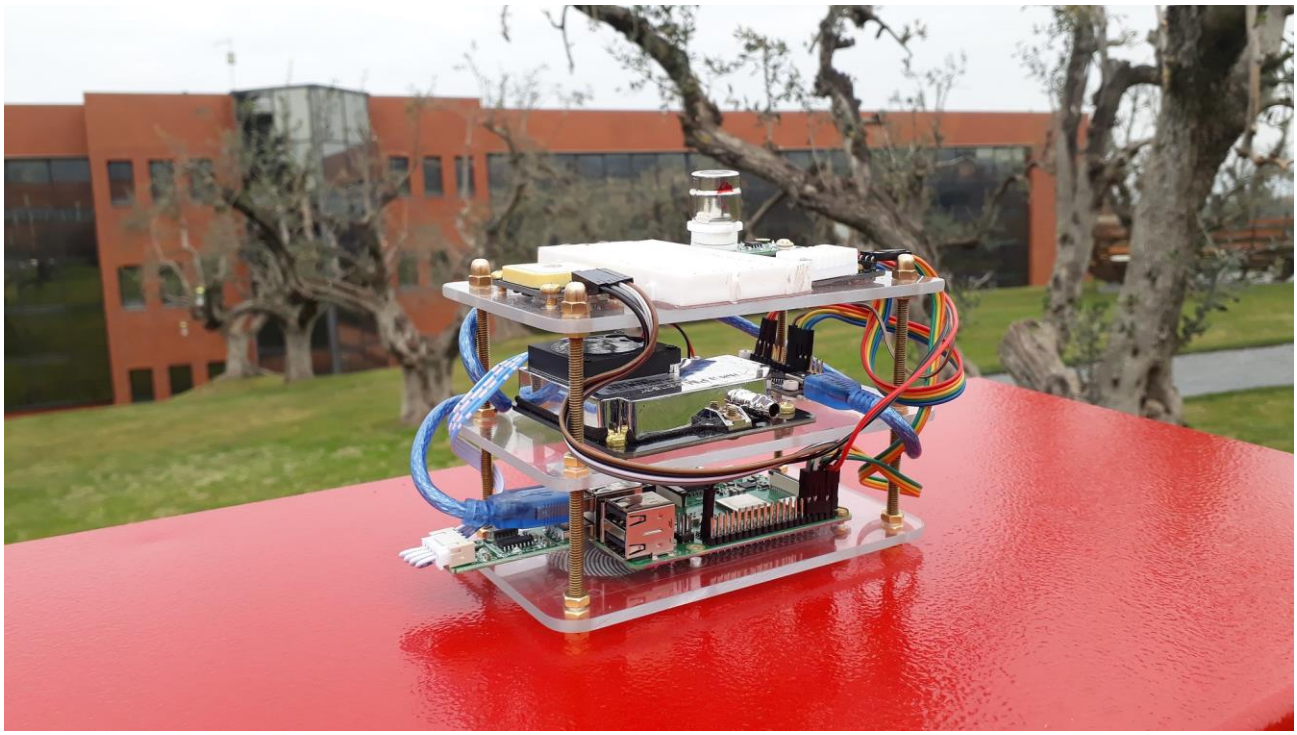
European Space Agency
Agence spatiale européenne



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GETTING STARTED

➔ Introduction

Air pollution is a serious problem worldwide, especially in urban areas. Did you know that, according to the World Health Organisation (WHO) some 4.2 million premature deaths each year are linked to air pollution? And did you know that 90% of people living in European cities are affected by air pollution at levels deemed harmful according to the European Environment Agency? If you want to learn more about this topic and investigate air quality in your city, the LPS Air Quality Station can help you do that!

The LPS Air Quality Station is a small computer equipped with a number of sensors which measure properties of the ambient air. It was developed by the European Space Agency (ESA) and can be used to investigate the air quality and learn about air pollution in an educational context. It measures some of the most important pollutants and greenhouse gases in our air such as NO_2, CO, CO_2 and particulate matter ($PM_{2.5}$ and PM_{10}).

Web map showing AQ Station measurements

The station is then able to send the acquired data to an ESA webserver where the measurements are visualized in real time on a dedicated web map (https://lps19airquality.esa.int/map/). Once the platform is assembled and configured following the indications given in this Quick Start Guide, and once an internet connection is available, it starts sending its measurements automatically. Using a web browser, you can access the map and see the position of your station and the acquired environmental values. All parameters are updated about every 60 secs. The LPS Air Quality Station can be controlled with a standard HDMI computer screen, USB mouse and USB keyboard or, alternatively, via Wi-Fi using VNC software.

This Quick Start Guide will show you, how to set up the station and how to make measurements with it.

➔ Hardware

The package you have received contains the LPS Air Quality Station consisting of the following hardware:

- Raspberry Pi 3B+: A small, credit-card sized computer that can be connected to a PC monitor and uses a standard keyboard and mouse (see also: https://www.raspberrypi.org/).
- Particulate matter (PM) sensor SDS011: Measures small particles in the air using a laser.
- Temperature and humidity sensor DHT22
- CO2 sensor MG811: A sensor that measures CO2 concentrations in the air.
- Microcontroller ELEGOO Nano V3.0: Works like a simple computer that has a processor, memory and digital and analog input and output pins. It serves to connect sensors with analog output to the Raspberry Pi.
- GPS module u-blox NEO-6M: A small GPS module which is used for positioning the station.
- NO2 sensor Mics-6814: A sensor that measures NO_2, CO and NH_3 concentrations in the air.
- Two-coloured LED to visually check internet connection and proper functioning of AQ Station
- 3 Plexiglas plates and screws
- A breadboard for the easy addition of sensors in the future

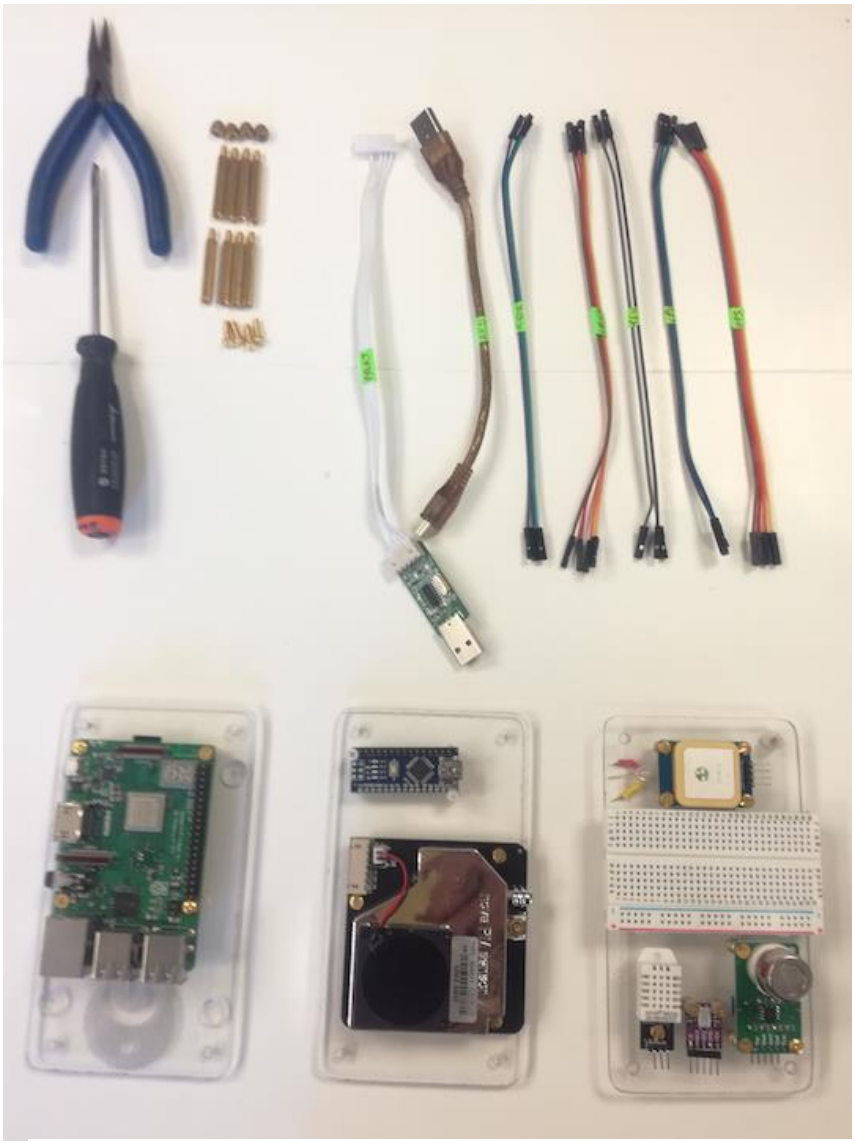
Furthermore, the package contains:

- Jumper wires
- USB cable to connect the particulate matter
- Micro USB cable to connect the microcontroller
- Power cable for the Raspberry Pi
- HDMI cable to connect the Raspberry Pi to your screen

IMPORTANT: You will need the following equipment:

- A PC screen with HDMI cable
- A USB keyboard
- A USB mouse
- Wi-Fi connection
- A power bank to make measurements outside (min. 10.000 mAh)
- A mobile phone for outdoor internet connectivity

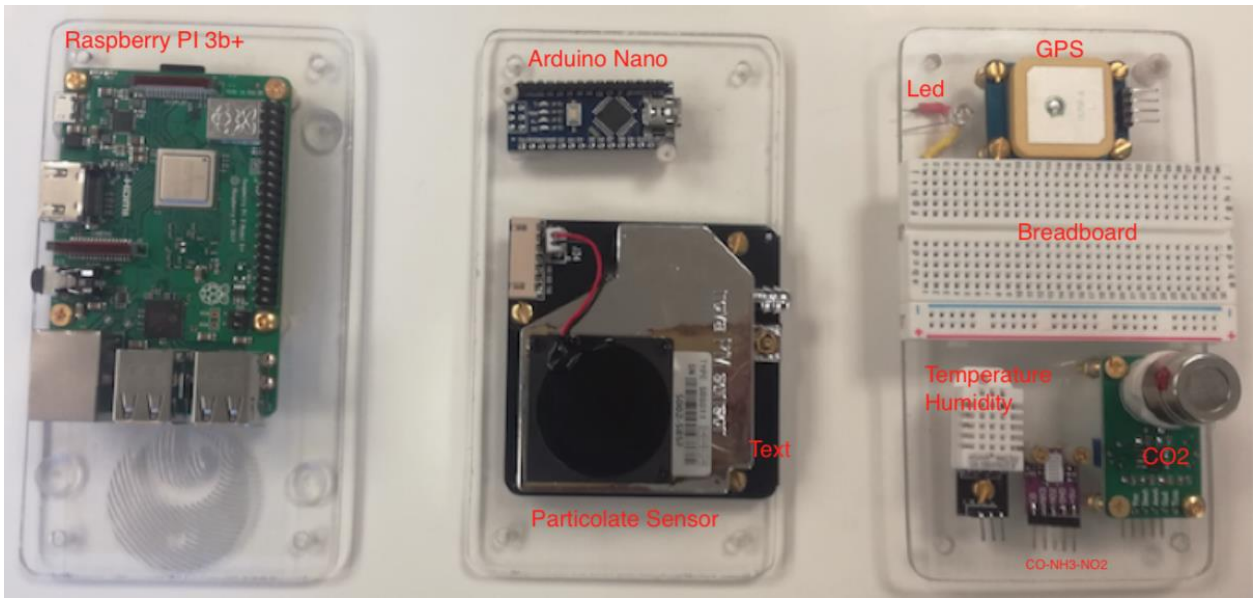
The station you received is unmounted into 3 layers as shown in the figure below:



Three layers of AQ Station plus cables, screws and tools (not included in delivery)

The three layers are:

1. Layer 1: Raspberry PI 3b+
2. Layer 2: Nano microcontroller and Particulate sensor (Nova PM Sensor SDS001)
3. Layer 3: Breadboard, Temperature & Humidity Sensor (DHT22), Co&NH3&No2 sensor (Cjmcu-Mics-6814), Co2 Sensor (Aihasd MG811 CO2 Carbon Dioxide), GPS receiver (XCSOURCE GPS NEO-6M), LED 2 colours (LED2Col).



Close-up of the three layers

Furthermore, 7 cables are included in the package. These are shown in the figure below:

Close-up of the 7 cables used to connect sensors

Each cable is identified with a green sticker label on it, stating its function. The cables are (from left to right): PM sensor USB cable (label: **PART**), Nano microcontroller micro-USB to USB cable (label: **ARD**), CO2 sensor jumper wires (label: **CO2**), NO2 sensor jumper wires (label: **CO NH3**), Temperature and Humidity sensor jumper wires (label: **T&H**), LED jumper wires (label: **LED**), GPS receiver jumper wires (label: **GPS**).

Furthermore, the package include the screws necessary to connect the 3 layers of the AQ Station. You will also need a screwdriver and a pair of pliers as shown in the figure below:

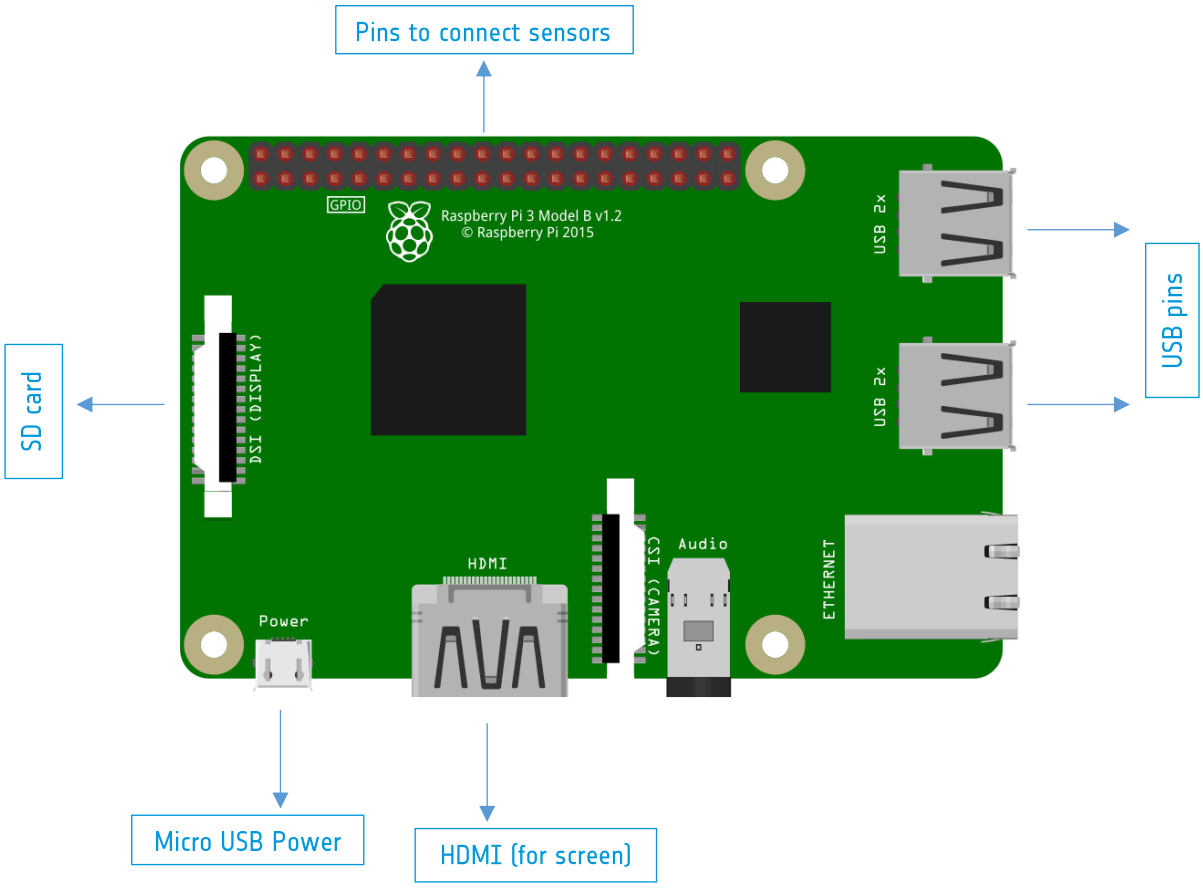
Mechanical tools and parts of the AQ Station

➔ Getting to know your Raspberry Pi

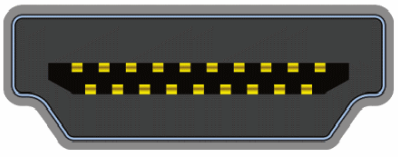
Before starting to connect the sensors, make yourself familiar with the Raspberry Pi. Raspberry Pi is a small computer, which works essentially like your desktop PC or laptop at home. The main difference being its small size. It can run software and even games, connect to the internet, play music or send emails. But it can also be used to conduct scientific experiments, do calculations, run scientific programs and collect data.

To interact with the Raspberry Pi, you need to connect it to a screen, keyboard and mouse just like a normal computer. You then have to connect the Raspberry to a power source either using the power cable provided or a power bank (which is useful if you want to be mobile with your Air Quality Station). **IMPORTANT: Do not connect the power cable to the Raspberry Pi before having connected all the sensors and having verified, that all the cables are connected correctly! Otherwise, you could destroy your Raspberry Pi!**

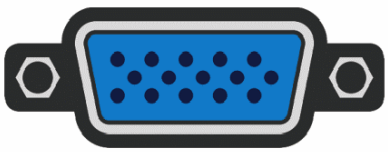
Below is a schematic of the Raspberry Pi. As you can see, it possesses a number of input and output pins. The SD card serves as the Raspberry's hard drive. Before you start, verify that the card is in its slot. Later, you will connect your USB keyboard and mouse to the USB pins and connect your screen to the HDMI pin using an HDMI cable.



Pay attention to you use the right cable when connecting to your screen! If you have an older screen, the input is likely VGA and not HDMI (see figure). In that case you need to use an adapter.



HDMI



VGA

ASSEMBLY OF AIR QUALITY STATION

IMPORTANT:

PLEASE FOLLOW THE INSTALLATION STEPS AS LAYED OUT IN THIS PARAGRAPH. DO NOT POWER ON THE AQ STATION BEFORE COMPLETING THE ASSEMBLY, THIS COULD DAMAGE THE PLATFORM OR SENSORS.

SEQUIRE LA SEQUENZA DI INSTALLAZIONE COME DESCRITTA IN QUESTO PARAGRAFO. NON ALIMENTARE LA STAZIONE PRIMA DI AVER FINITO L'INSTALLAZIONE. QUESTO PUO' CAUSARE LA ROTTURA DELLA PIATTAFORMA O DEI SENSORI.

➔ Connecting the sensors

Some of the instruments can be connected directly to the Raspberry Pi. These are:

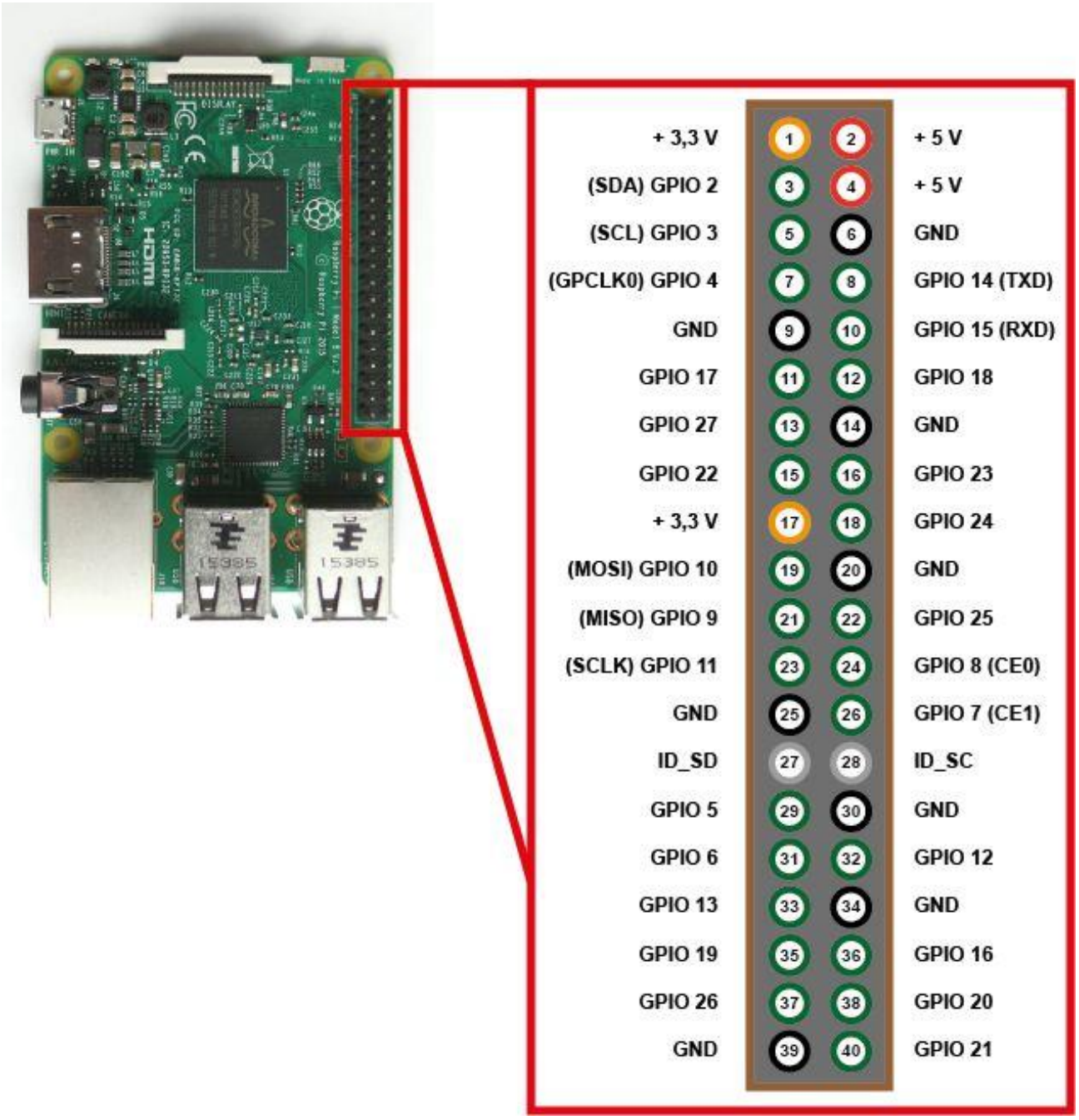
- the PM sensor
- the temperature sensor
- the GPS module
- the Nano microcontroller
- the LED

Other sensors have an analog output and must be connected to the analog pins of the Nano microcontroller. The microcontroller will then convert these values into a digital output which can be read by the Raspberry Pi. These are:

- the CO2 sensor
- the NO2 sensor

Furthermore, some of the sensors are connected using standard USB cables while others need to be connected using so-called jumper wires. In particular, the PM sensor and the Nano microcontroller are connected to the Raspberry Pi via standard USB cables. The other sensors use jumper wires.

The Raspberry Pi disposes of 40 pins to connect jumper wires. These are shown below with their respective number:



Next to the number of the pin, you can see its function. For example +3.3 V or +5 V indicates that this pin is used for power supply (of either 3.3 or 5 volts). GND stands for *Grounding* and is the return path for an electric current. GPIO means *General Purpose Input and Output*. These pins can be used for sending and receiving data and commands to and from the connected sensors.

Now that you are familiar with the Raspberry Pi and it's input and output pins, let's start assembling the station. Start with Layer 1 of the AQ Station:

Layer 1 of the AQ

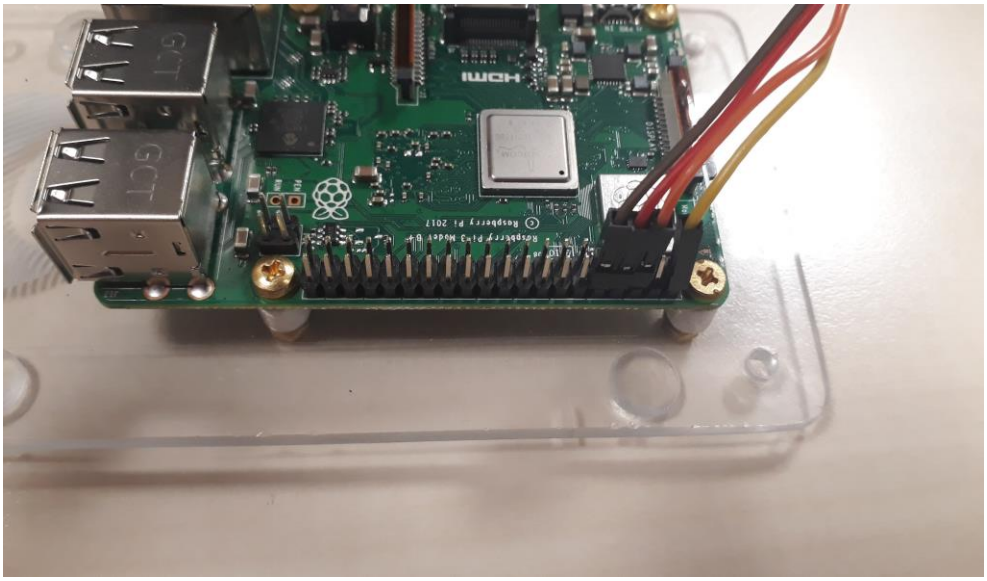
First we will connect the **GPS module**. Take the cable which is marked with GPS. This cable should have 4 jumper wires in yellow, orange, red and brown. Now connect one end of the cable to the pins of the Raspberry. The pin configuration is as follows (see also the figures):

Yellow -> pin 2 of the rasp PI (+5V)

Orange-> pin 6 of the rasp PI (GND)

Red -> pin 8 of the rasp PI (GPIO14)

Brown -> pin 10 of the rasp PI (GPIO15)



GPS cable connection

Now continue to connect the **LED cable** to the Raspberry. This cable consists of 3 jumper wires which should be violet, blue and green.

Violet -> pin 34 of the rasp PI (GND)

Blue -> pin 36 of the rasp PI (GPIO16)

Green -> pin 38 of the rasp PI (GPIO20)

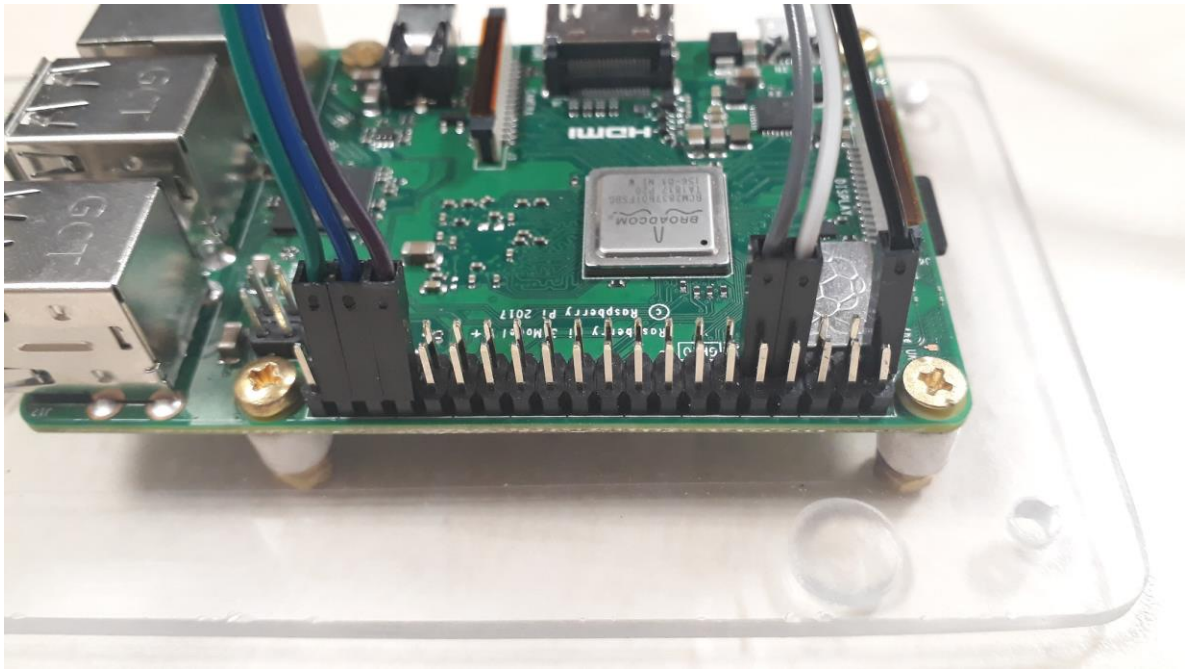
LED cable connection

The **Temperature and humidity sensor** is connected to the Raspberry via a black, white and grey cable. Connect the Temperature & Humidity cable to the Raspberry PI as depicted in the following figure.

Black -> pin 1 of the rasp (+3.3V)

White -> pin 7 of the rasp (GPIO 4)

Grey -> pin 9 of the rasp (GND)



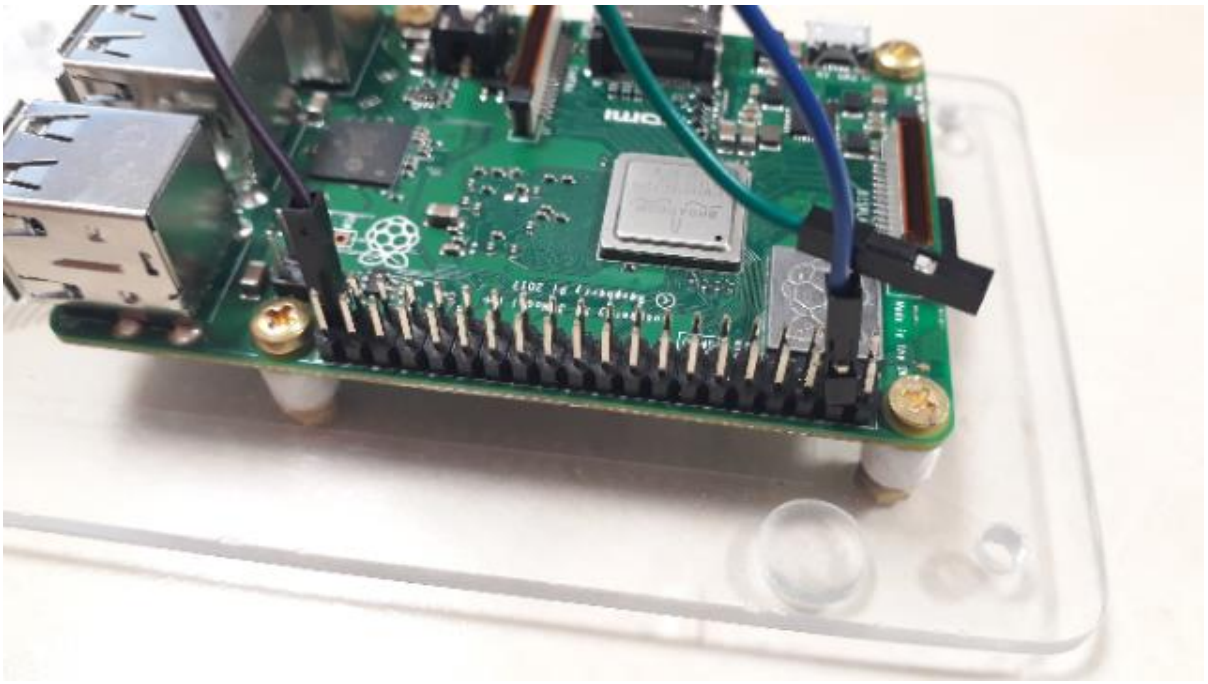
Temperature and humidity sensor cable connection (GPS has been removed temporarily for better illustration)

Connect the **CO2 sensor** cable to the Raspberry PI as depicted in the following figure.

Violet -> pin 39 of the rasp (GND)

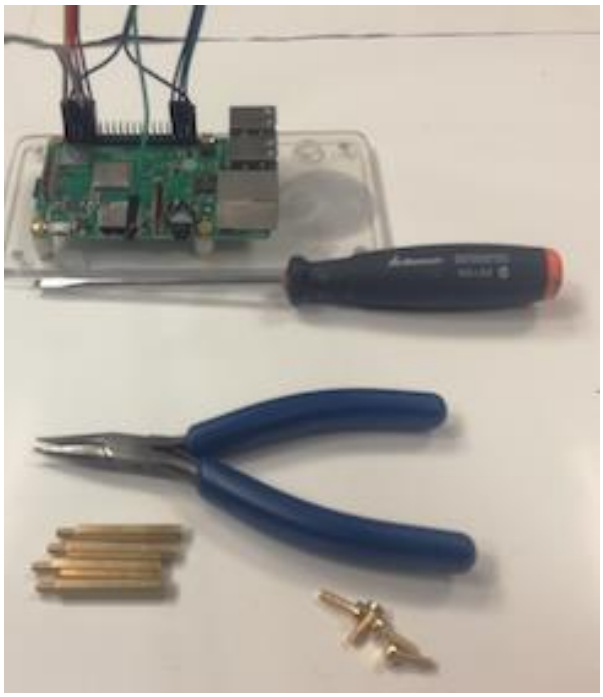
Blue -> pin 4 of the rasp (+5V)

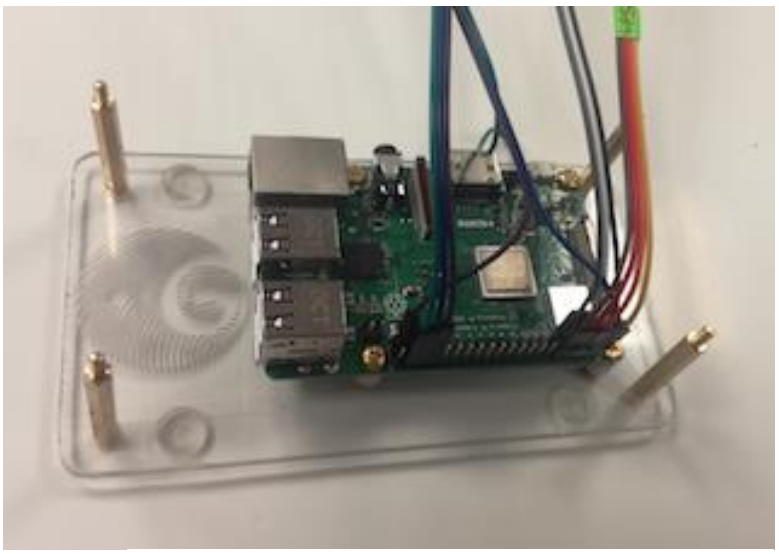
Green -> Don't connect yet, leave it free



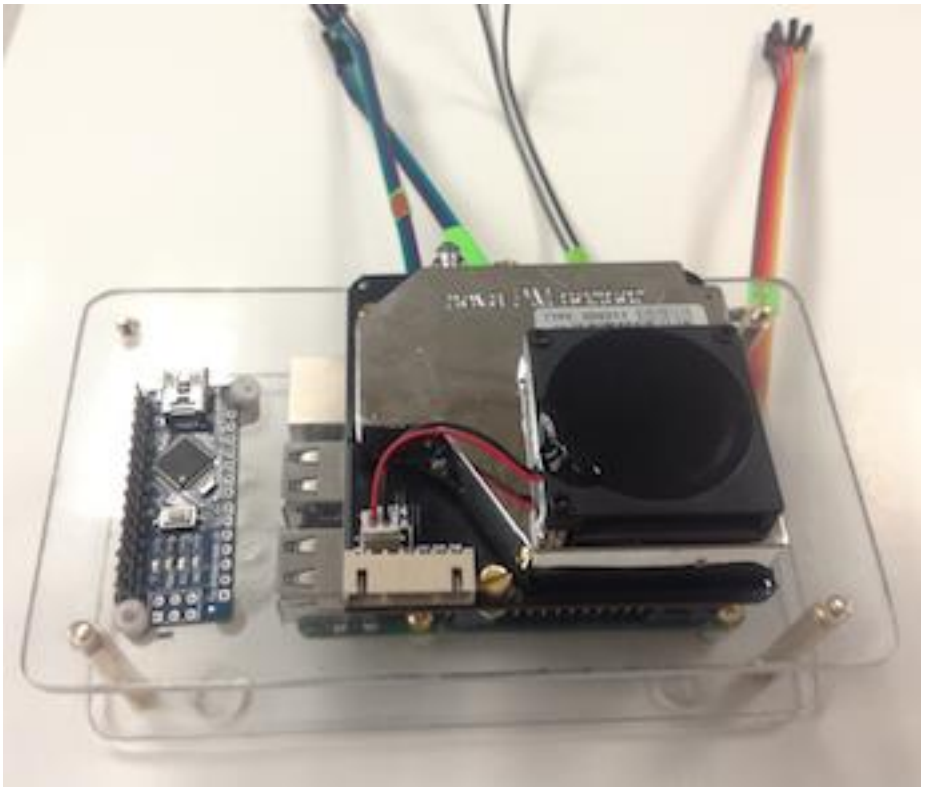
CO2 sensor cable connection (other sensors have been removed for better illustration)

Now that the sensor cables are connected to the Raspberry Pi, we will proceed with the mounting of level 2. First, mount the turrets on layer 1, then mount layer 2 on layer 1 using the provided screws and turrets as shown in the following figures:



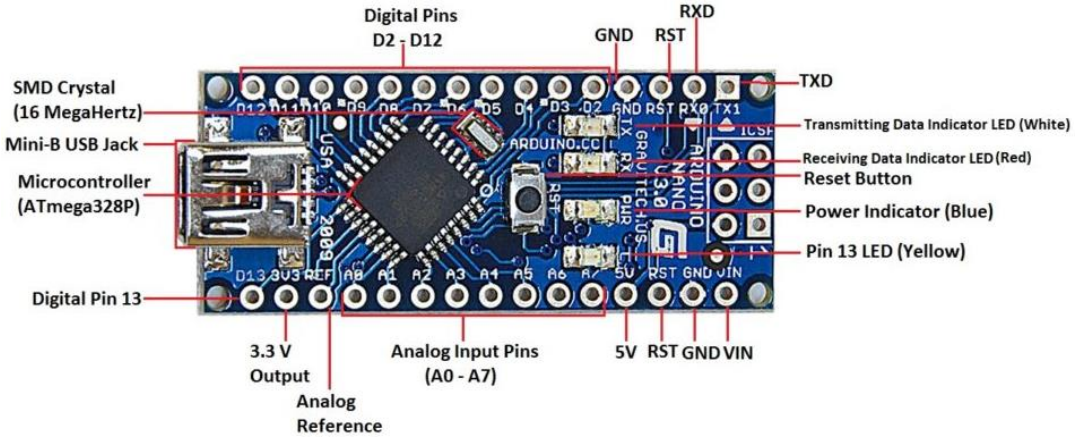


Turrets are mounted on layer 1 using the provided screws



Layer 2 mounted on top of layer 1

Make sure, that the cables are lying outside as shown in the picture above. Otherwise, you may have difficulties connecting the sensors. Layer 2 contains the particulate matter sensor and the nano microcontroller. The microcontroller's pins are described in the figure below:



We will now proceed to connect those sensors, which have an analog output, to the microcontroller. In particular, two sensors have to be connected to the microcontroller: the CO2 and the NO2 sensor. Take the NO2/CO/NH3 sensor cable. This should be five jumper wires connected together in the colours green, yellow, orange, red and brown. Also, take the loose green cable from the CO2 sensor. The configuration should be as follows:

CO-NH3-NO2

Green -> pin VIN nano microcontroller

Yellow -> pin GND nano microcontroller

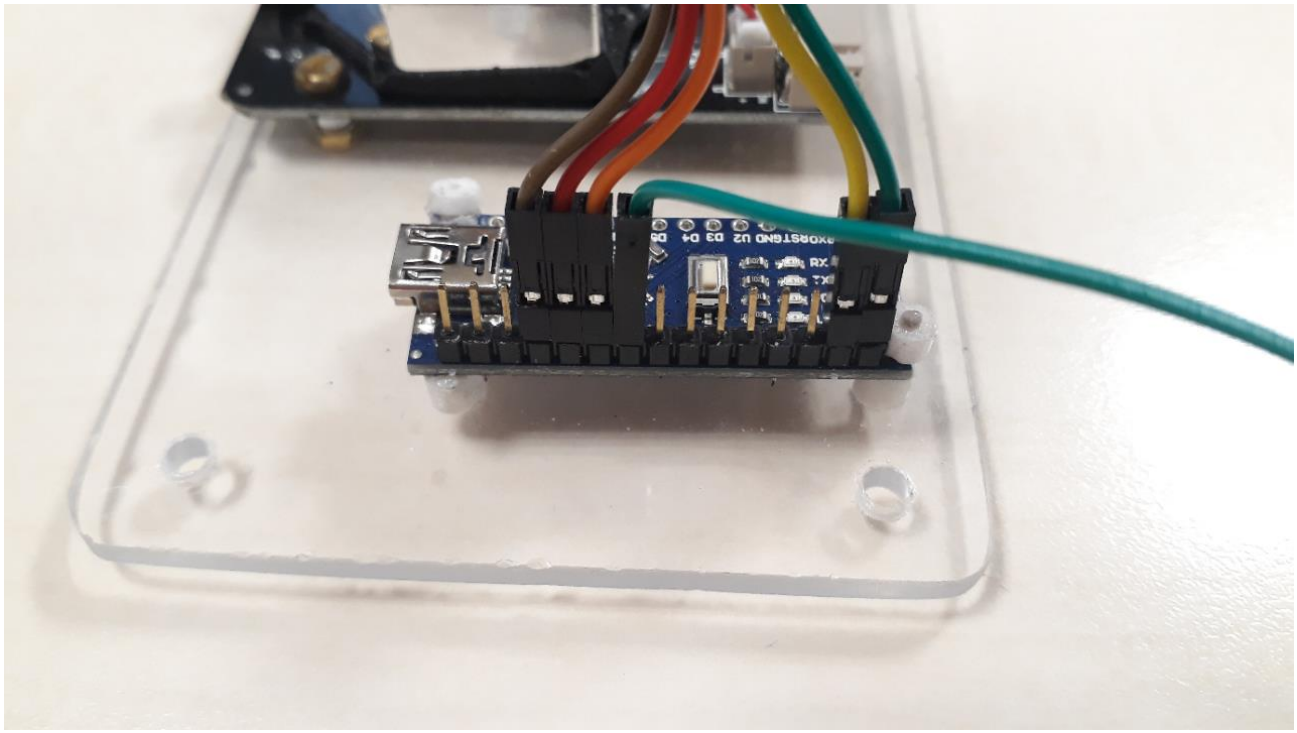
Orange -> pin A2 nano microcontroller

Red -> pin A1 nano microcontroller

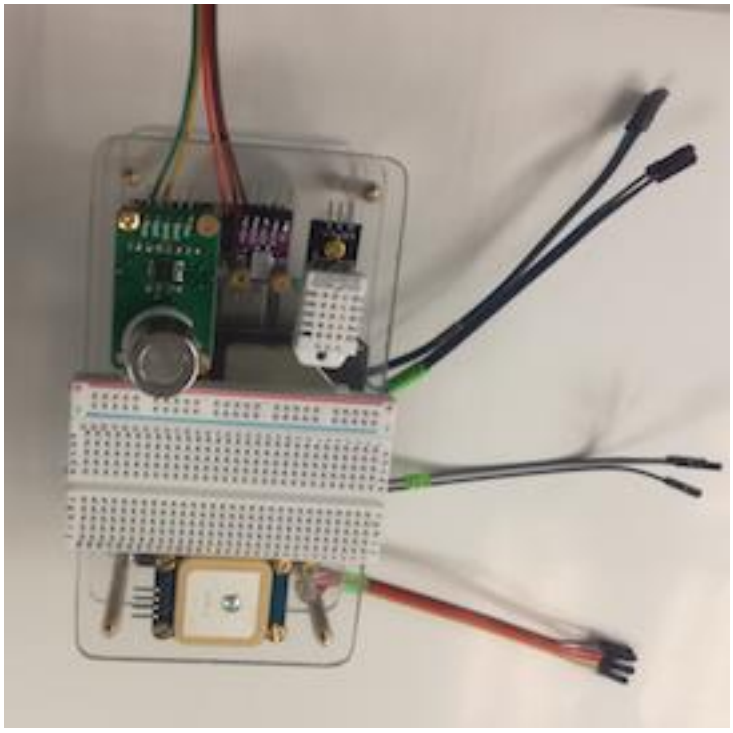
Brown -> pin A0 nano microcontroller

CO2

Green -> Arduino nano pin A3



Now mount layer 3 on top of layer 2. To do that, insert layer 3 in the turrets as depicted in the figure below. Then put the screws on the turrets. Again, take care that any loose cables are lying outside of the station as is shown in the photo.



Layer 3 mounted on layer 2. Pay attention to the position of the cables.

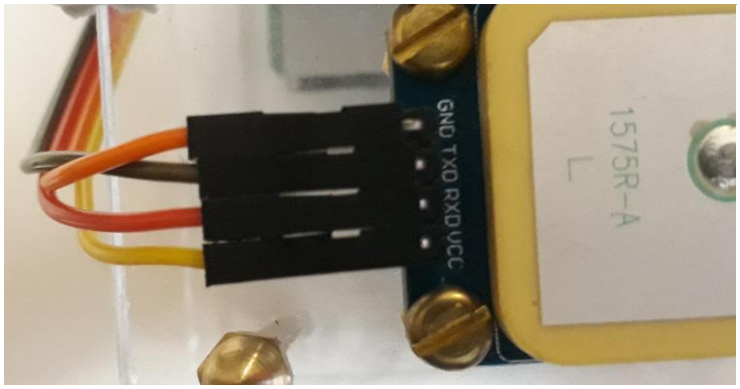
Now that all 3 layers are connected, the loose cables need to be connected to the sensors. First, connect the GPS cable to the GPS as depicted in the next figure. The configuration is (pay attention to the small labels next to the pins of the GPS receiver):

Yellow -> pin 1 from right (VCC)

Red -> pin 2 from right (RXD)

Brown -> pin 3 from right (TXD)

Orange -> pin 4 from right (GND)



Connection of the GPS receiver. The pin functions are indicated on the sensor (GND – ground, TXD – digital transmit, RXD – digital send, VCC – power)

Connect the LED cable to the LED as depicted in the next figure.

Violet -> central LED pin (GND)

Blue -> red LED pin (indicates that the sensor is working)

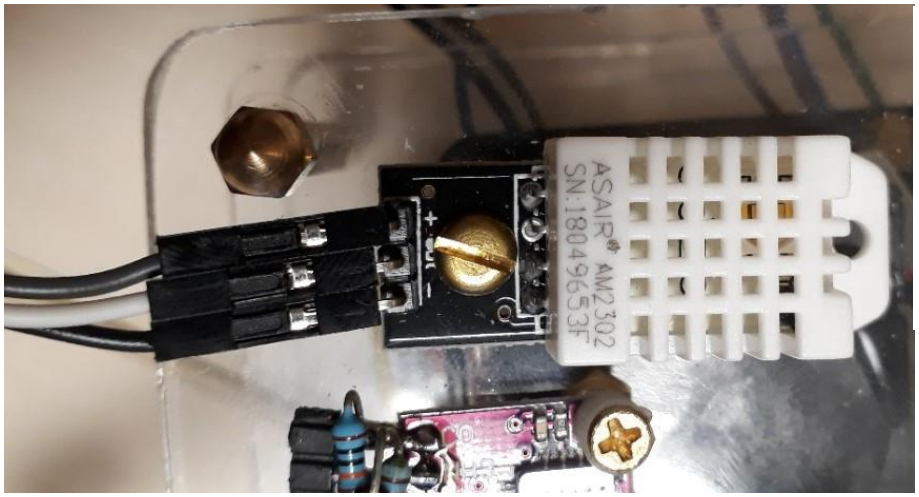
Green -> yellow LED pin (indicates that Wi-Fi is active)

Now, connect the corresponding cable to the temperature and humidity sensor as shown in the image:

Black -> pin 1 (VCC or +)

White -> pin 2 (OUT)

Grey -> pin 3 (GND or -)



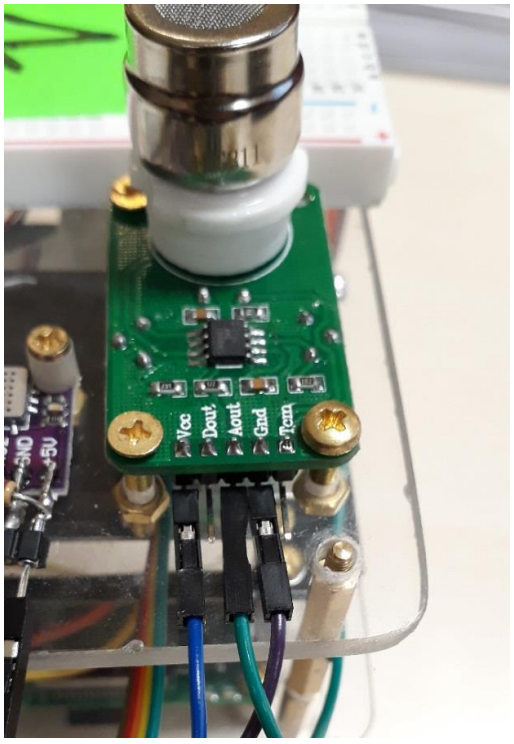
Connection of the T&H sensor. Pay attention to the little inscriptions on the sensor (here: +, out, -). They indicate the function of the pins.

When connecting the CO2 sensor, you might have to slightly unscrew the screws holding the sensor (allentare viti del sensore) and tighten it again once the cables are connected (stringere viti sensore). The configuration is:

Violet -> pin 2 from right (GND)

Green -> pin 3 from right (Aout)

Blue -> pin 5 from right (VCC)



CO2 sensor connection. Pins are indicated on the sensor.

Finally, connect the CO-NH3-NO2 sensor.

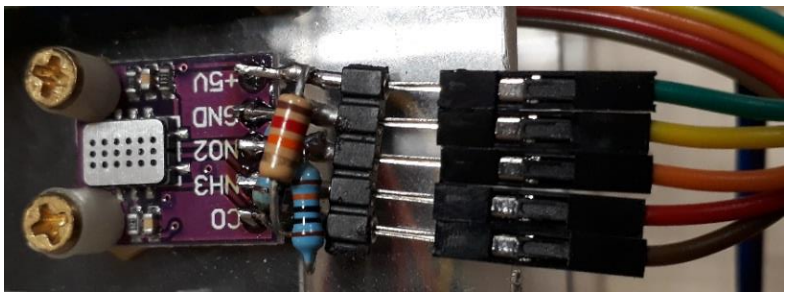
Green -> pin 1 from right (+5V)

Yellow -> pin 2 from right (GND)

Orange -> pin 3 from right (NO2)

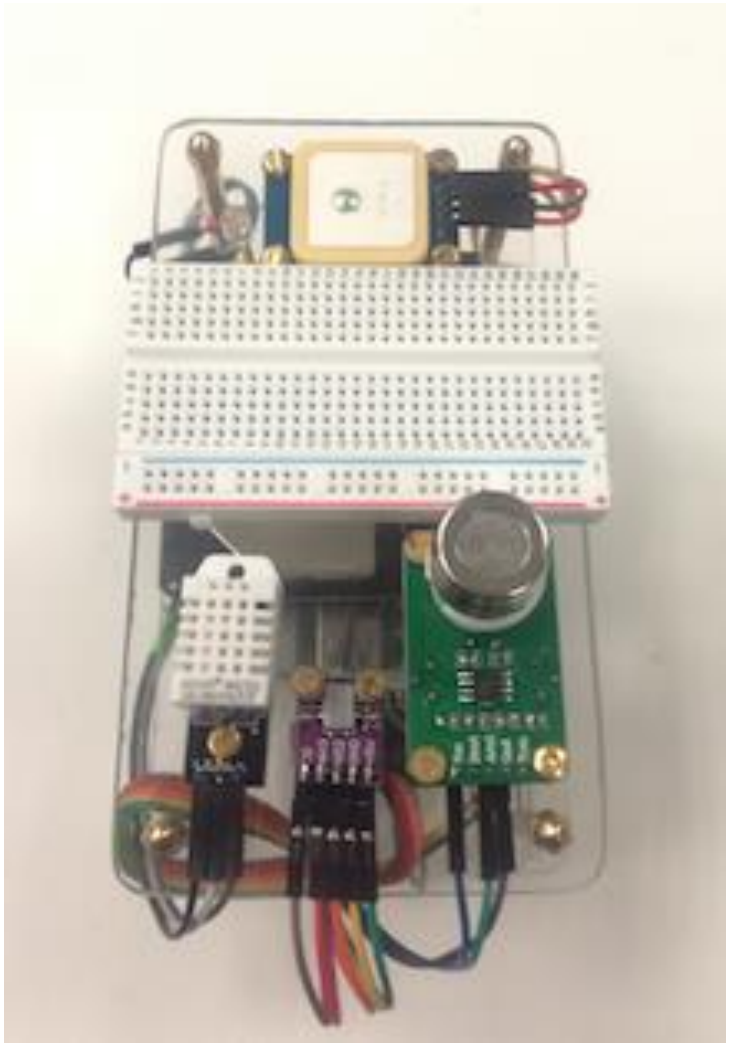
Red -> pin 4 from right (NH3)

Brown -> pin 5 from right (CO)



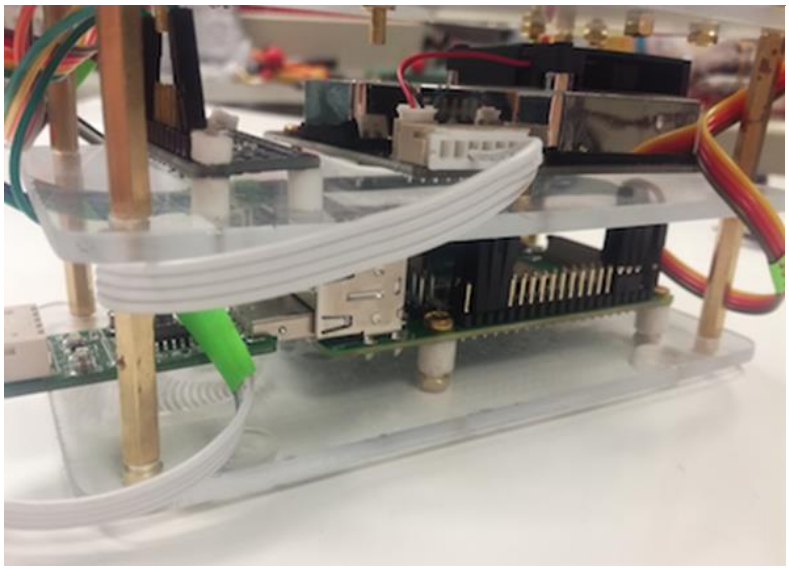
NO2 sensor connection.

Your layer 3 should now look like in the figure below.

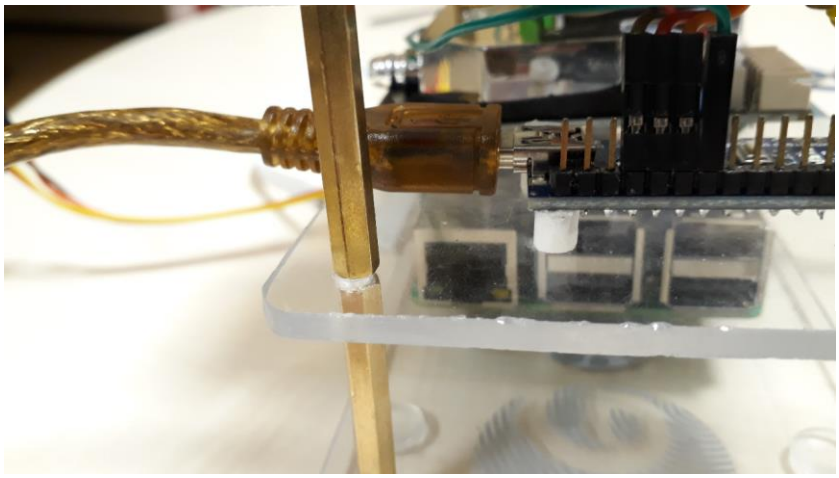


Cable connections in layer 3 overview.

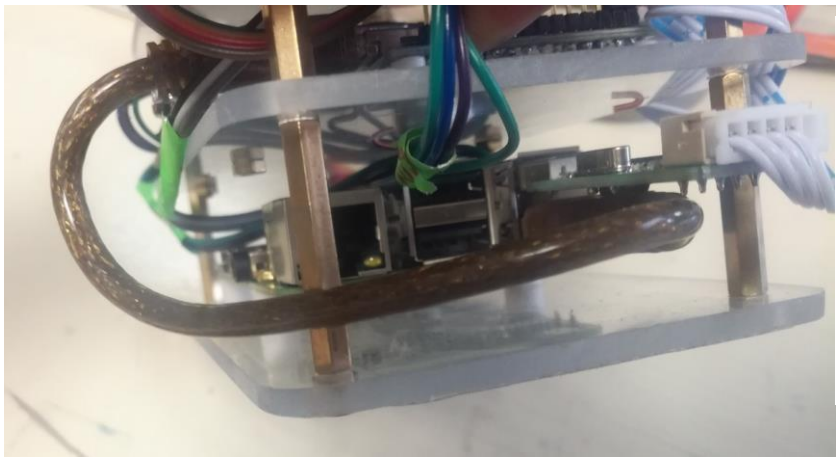
Now, connect the white USB cable to the PM sensor and the USB end to the Raspberry Pi and connect the mini-USB to USB cable to the microcontroller and then to the Raspberry Pi with the USB end of the cable as shown in the next figures. When connecting the USB cables to the Raspberry's USB ports, pay attention that the microcontroller is connected to the right lower port and the PM sensor to the right upper port as shown in the figure.



Connecting white USB cable to PM sensor.



Connecting micro-USB end of micro-USB to USB cable to nano microcontroller.



Connecting PM Sensor and microcontroller USB cables to Raspberry Pi.

Attention: Microcontroller is connected to the lower right port, PM sensor to upper right port!

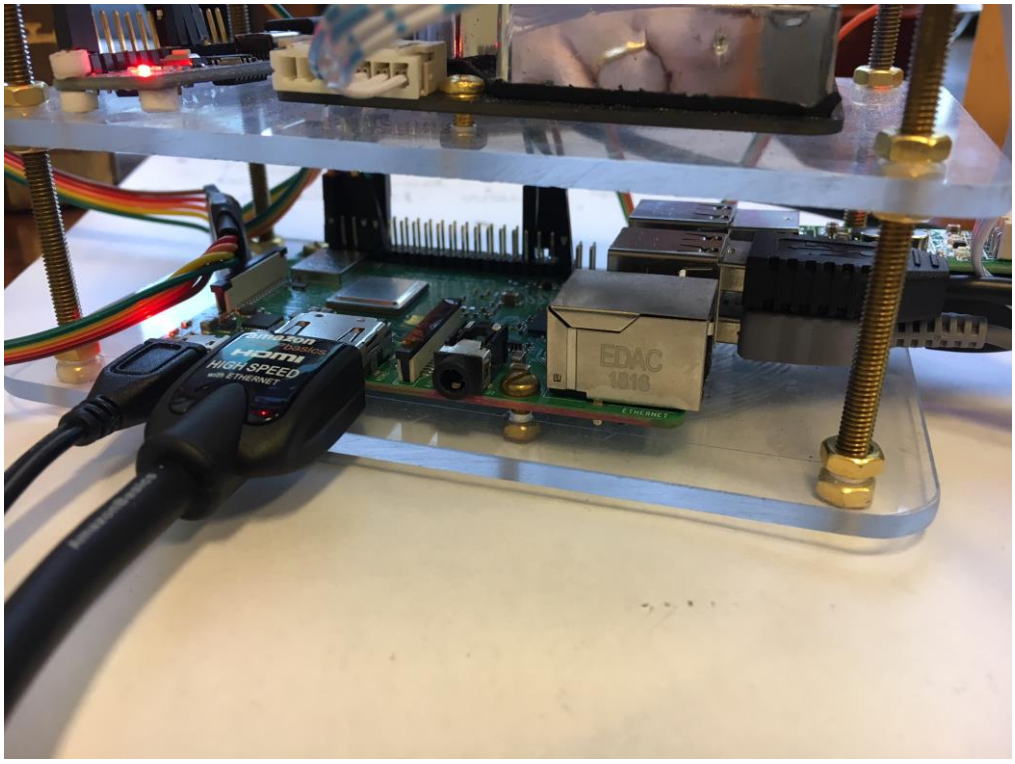
TESTING AND CONFIGURING THE STATION

NOTE:

NOW THE AQ STATION IS READY TO BE CONNECTED TO THE TO THE POWER SUPPLY. BEFORE DOING THAT PLEASE VERIFY THAT ALL THE CONNECTIONS HAVE BEEN DONE PROPERLY BY REHEARSING ALL THE PREVIOUS STEPS. IN CASE A PIN CONNECTION HAS BEEN MISTAKEN, DAMAGE MAY OCCUR TO SENSORS OR TO CONTROLLERS.

ORA LA STAZIONE AQ È PRONTO AD ESSERE ALIMENTATO. PRIMA DI FARE CIÒ PER FAVORE VERIFICARE CHE TUTTE LE CONNESSIONI SONO STATE EFFETTUATE CORRETTAMENTE. NEL CASO IN CUI UNA CONNESSIONE TRA PIN È ERRATA, SI POSSONO AVERE ROTTURE DEI SENSORI O NEI CONTROLLORI.

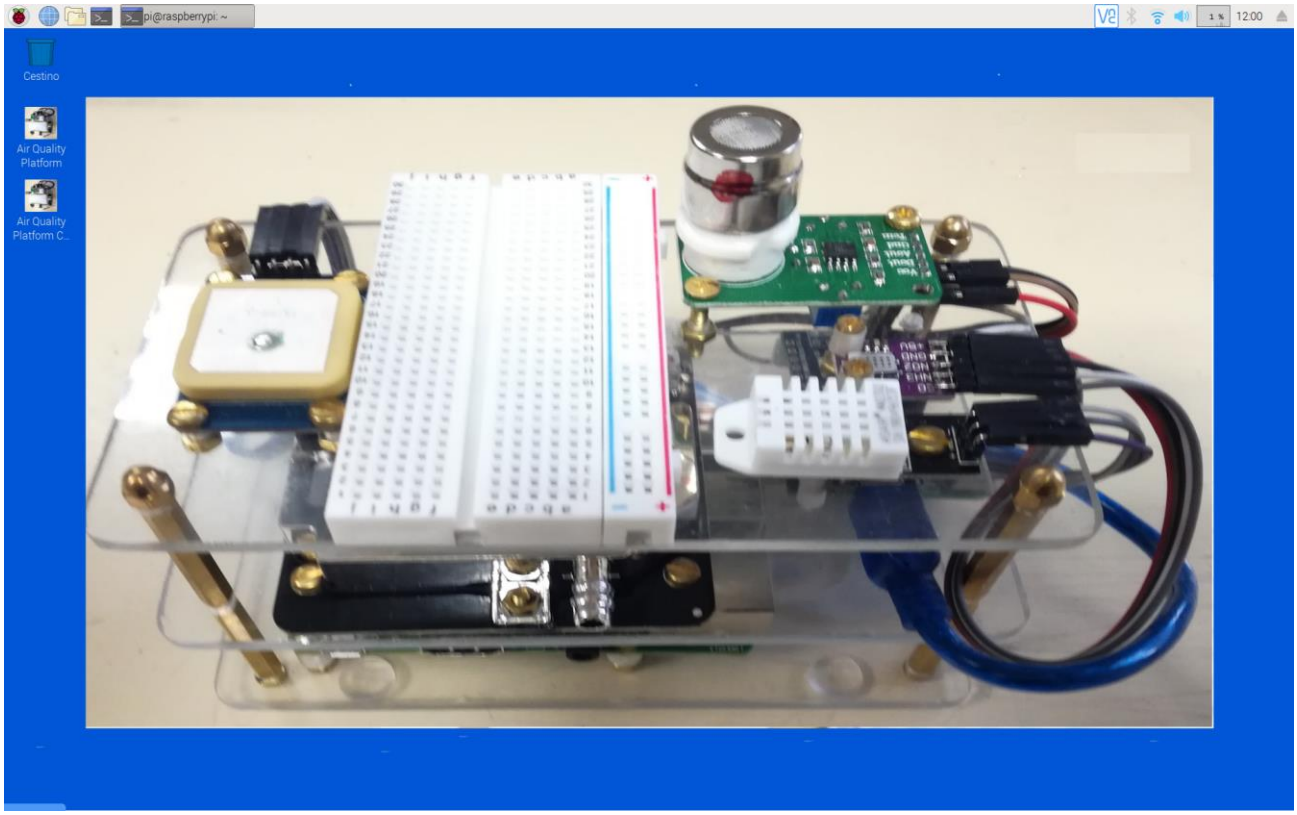
Once all the sensors are properly connected, connect a screen to the HDMI pin of the Raspberry and mouse and keyboard to the two free USB pins. Verify that the micro SD card which serves as the Raspberry's hard drive is in its place. Now connect the power cable to the micro-USB port of the Raspberry. The following picture shows you how the connections should look like:



Screen, keyboard, mouse and power supply are connected

➔ Set up Wi-Fi connection

Once the keyboard, mouse and screen are correctly connected and the SD card is in its place, you can start your Raspberry by connecting the micro USB power cable. It can take up to 5 minutes for the Raspberry Pi to boot. You should see it flash and on your screen you should now see some text appearing. Once the Raspberry Pi has started, you should see the graphical interface:



Start screen of Raspberry Pi

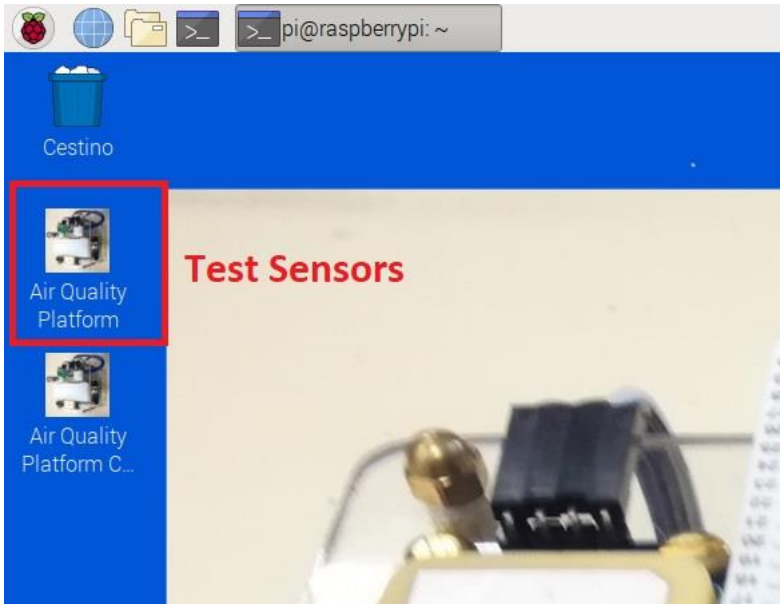
You can now start to use your Raspberry Pi. The first thing you should do, is set up an internet connection. To do that, click on the network button in the upper right, choose the network you want to connect to and enter your credentials. Open the web browser and verify, that you have an internet connection.

➔ Run test routine

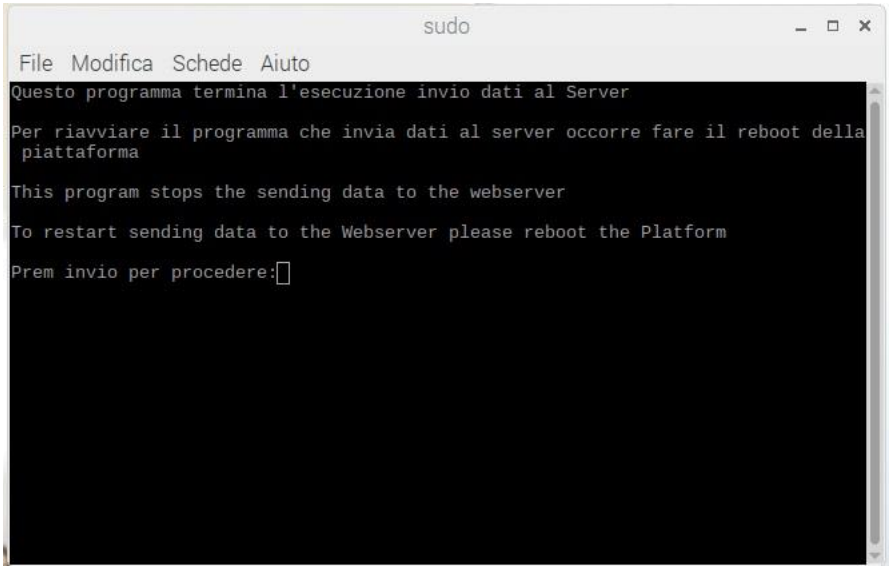
The station is configured in such a way that it automatically starts sending data to our web server once all the sensors are connected and an internet connection is available. You will now run a test routine to verify, that you made no mistakes when connecting the sensor. This routine will temporarily suspend the sending of data which will only start again, once the test routine has been run and the Raspberry has been rebooted.

Before you do that, make sure that the LED in the top layer of the station is blinking. The LED has two colours: red and yellow. When the red LED blinks with a period of more than one second, it means that the station is acquiring data, if it blinks with a period less than one second, the station is waiting for the next acquisition. If the red LED does not blink (always on or always off), the station is stuck and may require action. The green LED on the other hand, indicates that you are properly connected with the internet when it is on. When the green LED is off, check your internet connection!

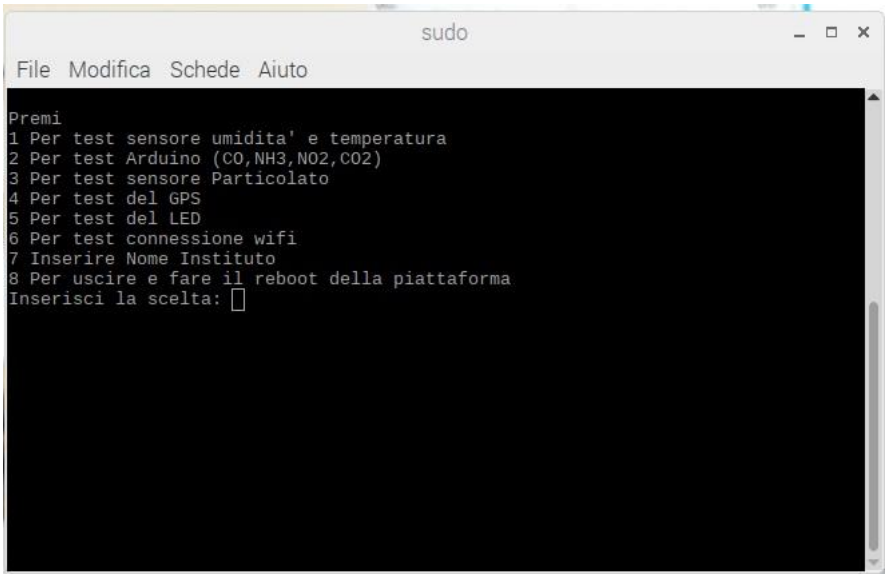
Start the program *Air Quality Platform* by clicking on the icon on the desktop. As mentioned, this program stops the execution of the Main Platform program and the sensors data is not sent to the webserver any more. To restart the Main program reboot the platform or exit from this program selecting the option 8.



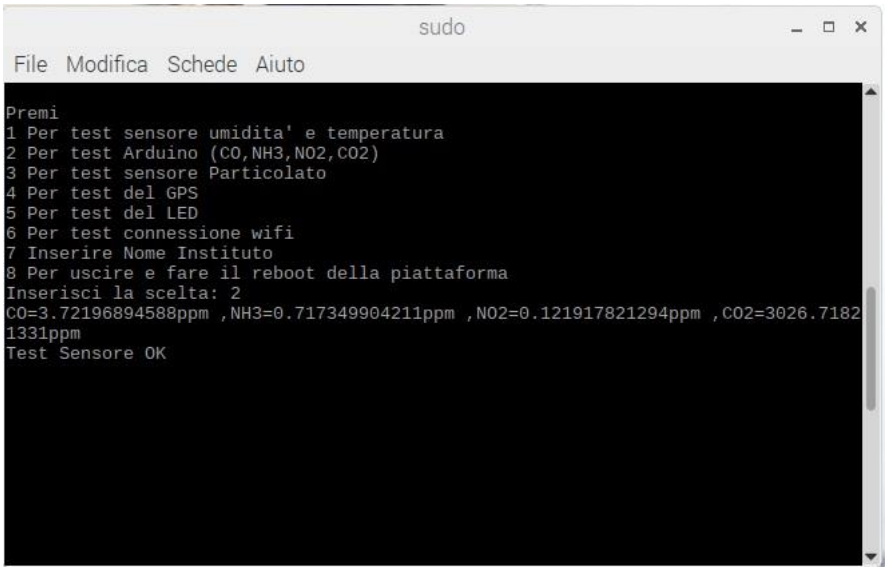
Once you have started the program, the following message will pop up. Click enter to continue:



Now the test program will start and you should see the following dialog:



Test the different sensors and the Wi-Fi connection by pressing the numbers 1 to 6. Below is an example output after testing the Arduino (the microcontroller):



The program will show you the current sensor reading and will display the message 'Test Sensore OK'. If this message is not showing or you are getting an error instead, check that the sensor is correctly connected. In the case of the LED, there is no message 'Test Sensore OK' displayed. Instead, the LED will blink red and green (so this is a purely visual test unlike the tests for the other sensors). For the GPS the test will show 'Test Sensore OK' when the GPS is working.

This does not mean however, that your position could be calculated. **For the GPS receiver to calculate your position you need to be outdoors or at least next to a window**. The position you see when testing the GPS is the **last known position**. Since all sensors where tested by the Esrin lab, the last known position may be in or around Frascati.

Once you have tested all the sensors and the Wi-Fi connection, enter the name of your school by pressing the number 7 on your keyboard and then end the program and reboot your Raspberry by pressing 8.

➔ Correct sensor measurements

Once the platform is set up and you have tested that all the sensors are working properly, you need to correct the sensor readings. In particular the two gas sensors (NO_2 and CO_2) have to be calibrated to make sense of their measurements. This is due to several phenomena: first of all, these electrochemical sensors are sensitive to a wide variety of gases (so-called cross-sensitivity) so they need to be put in an environment with a known gas distribution to figure out the contribution of each gas to the measured signal. Secondly, under different environmental conditions (different temperature and humidity etc.) the sensor readings can change, even if the gas concentration has not changed.

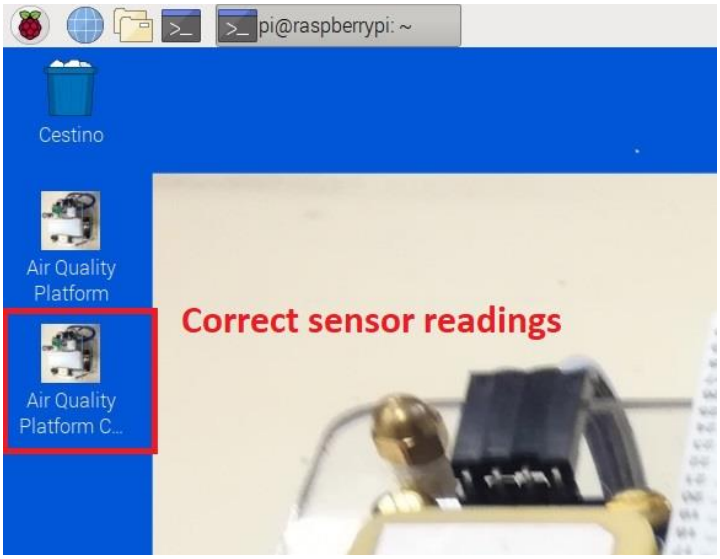
Due to the complex nature of the problem, a calibration of your sensor conforming to scientific standards **is not possible in the scope of this project**. Instead a rough 'correction' of your measurements will be performed. To do so, you will put the platform in an atmosphere where the gas content is approximately known. For example, we more or less know the concentrations of CO_2, NO_2, NH_3 and CO in clean air (for this experiment we assume that if you are outdoors and away from cars and streets, the air can be considered 'clean').

The idea behind this simple correction is that, if the quantity of a certain gas y_0 in clean air is known (for example, for CO2 y_0~400ppm), the relationship between the voltage x_0 output by the sensor in clean air and the quantity of gas in the air can be described by a line equation:

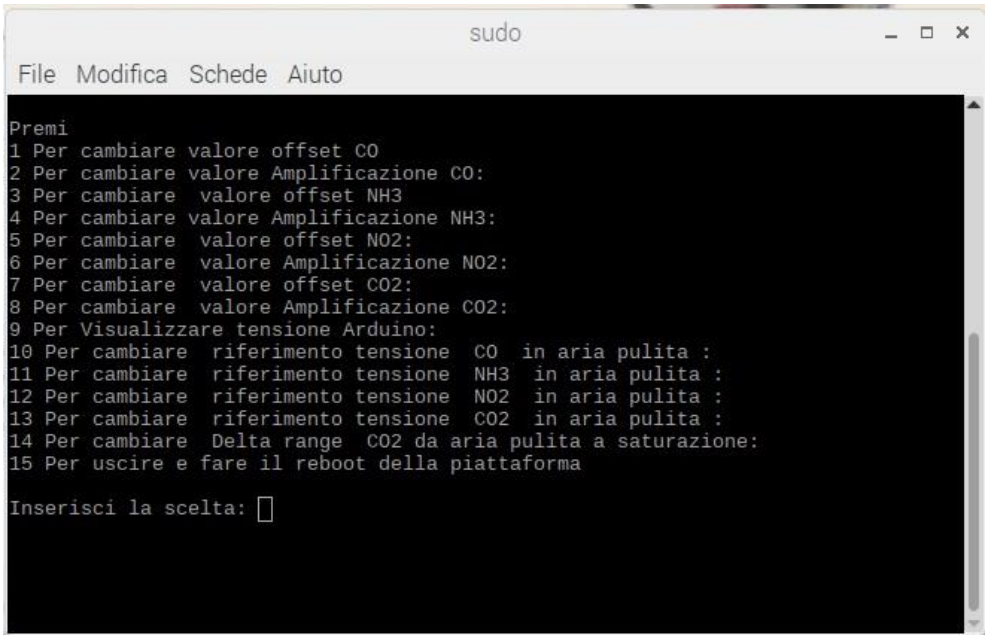
$$Y_0 = ax_0 + b$$

Where y_0 is the (known) quantity of gas in clean air, a is the amplification, b is the bias and x_0 the voltage output by the sensor. a and b have been estimated by us. In general, you will only need to update the value x_0 for your case.

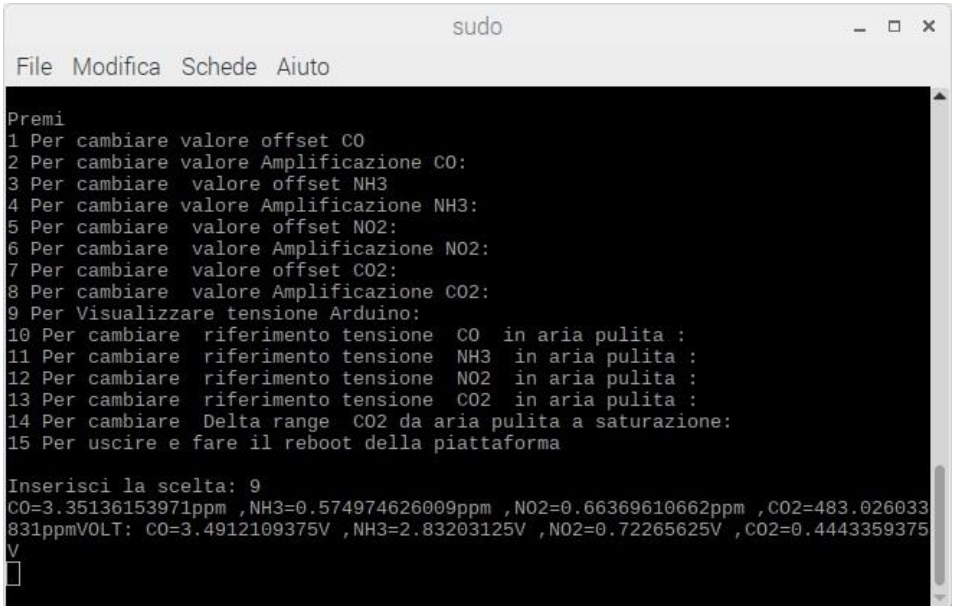
Place your sensor outdoors or next to an open window (pay attention that there are no cars in the immediate vicinity of the sensor). Now run the program *Air Quality Platform Correction* by clicking on the symbol on the Raspberry's desktop:



You should now see a message pop up which explains, that running this program temporarily suspends the sending of data to the web server and that you'll have to reboot your Raspberry Pi after doing the correction. Continue by clicking enter. Now the following dialog appears:



Press 9 to visualize the voltage read by the Arduino Nano.



You now see the measured voltage in (approximately) clean air for the 4 gases measured by the LPS Air Quality Station. Copy these values (if they disappear, scroll up in the terminal) and enter them each as x_0 for the respective gas. For example, copy the measured voltage for CO_2 (here: 0.4443...) enter 13 '*Per cambiare riferimento tensione CO2 in aria pulit*a' paste the value and confirm by pressing

enter. Do this for all 4 gases! Normally, you don't need to change neither the bias nor the amplification! If you want to see, how your sensor readings are changing, you can run the test routine before and after updating the reference voltage and display the measured gas concentrations. On top of that, for CO_2, the option was added to define the range of voltage variation of the sensor. By entering 14, you can change the voltage delta between the minimum condition (in clean air) and maximum condition (when the sensor is saturated).

Please also note that the gas sensors need some time before they reach their operational temperature. The best solution is to leave your sensor running for a day and then update the reference voltage values.

➔ Check that your data is online and see your measurements

You can see your measurements on our website https://lps19airquality.esa.int/map/ in a real-time web map. This map is updated every 60 seconds and you can always see the current and historic measurements of your sensor.

TAKING MEASUREMENTS

➔ Setting up the station

Once you have connected the station to Wi-Fi, have connected and tested all the sensors and have started the manager.py program, your Air Quality Station is ready for work! You have essentially two options: you can have the station at a fixed location, or you can take it with you and do measurements in different locations.

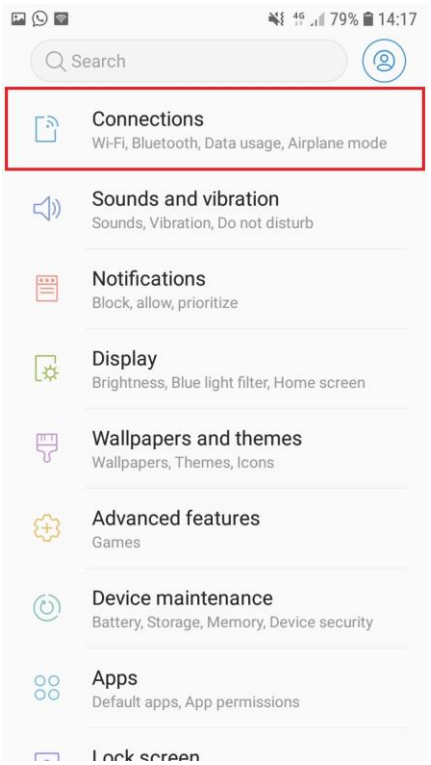
➔ Fixed location

Place the station in a location outdoors where it is protected from rain and direct sunlight and where you can connect it to a power plug. You also need a Wi-Fi connection (the one you set up earlier!). An ideal location would be for example next to a window or on a terrace or balcony. Once the station is in its location, connect the power cable to the power plug. Now the Raspberry Pi will boot and start the manger.py program automatically and start sending data to the server located at api.lps19airquality.esa.int. You can see your measurements in real-time on our online map and use the LED to verify the correct functioning of your station.

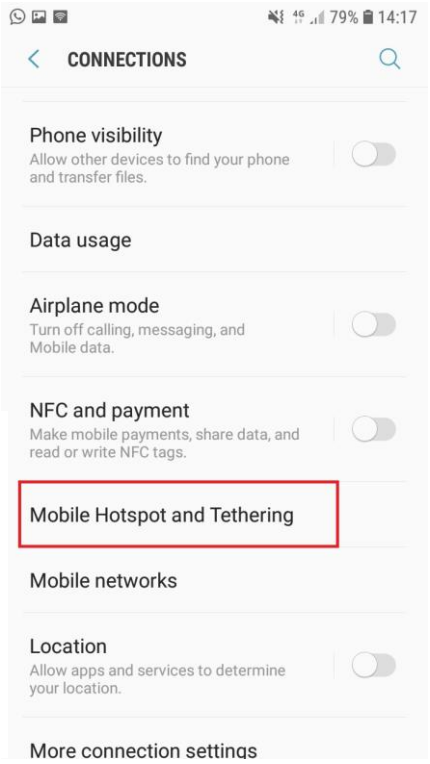
➔ Mobile station

If you want to take your station with you and make measurements around the city, you need a power bank in order to be able to power the station (at least 10.000 mAh). With a power bank, your sensor should be able to take measurements for a few hours before it runs out of power. To make sure you have a Wi-Fi connection while your outdoors with your sensor, it is a good idea to tether the mobile connection of your smartphone. In that case, use the Wi-Fi name and password provided by your mobile phone when setting up the station. Here is a link to a tutorial describing how to do mobile tethering for Android phones: https://support.google.com/nexus/answer/9059108?hl=en and IPhones: https://support.apple.com/en-us/HT204023

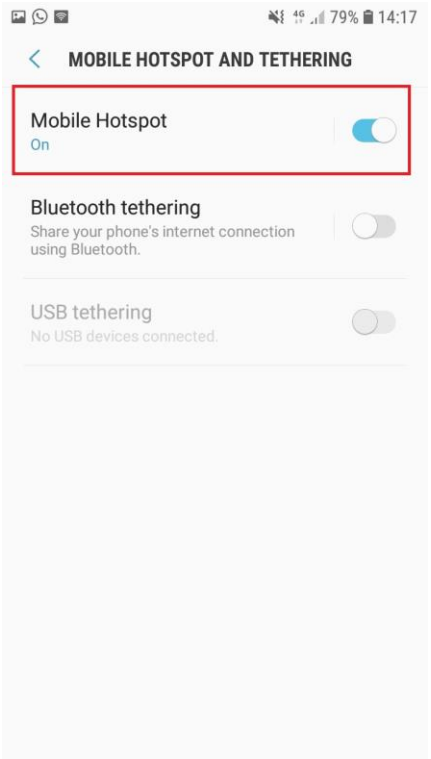
Typically, for an Android phone, you can follow the steps shown below:



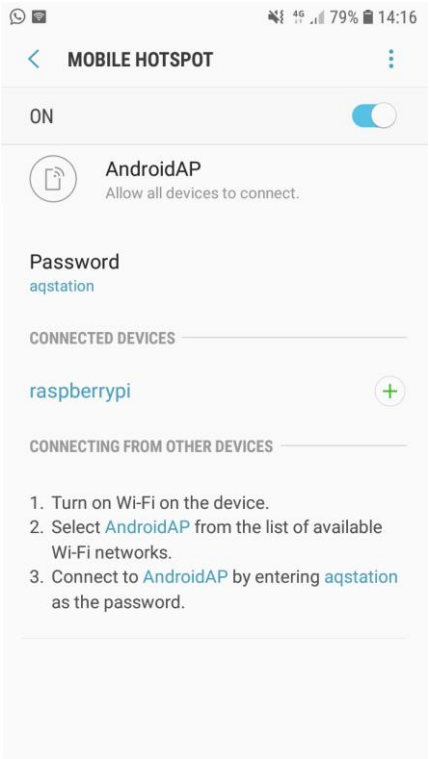
1. Go to Settings -> Connections



2. Select Mobile Hotspot and Tethering



3. Turn on the option 'Mobile Hotspot'



4. Go inside the mobile hotspot settings. Here you can set the network name and password. You can also see, which devices are connected. Connect your Air Quality Station to the network using the name and password you set up here. Now you can walk around with your station and use the internet from your phone to send your data.

While being mobile with your station, you can use the LED to check its proper working.

TECHNICAL SUPPORT

For urgent technical support about the AQS, you can contact ESA directly from 10:00 to 12:00 during working days at the phone number +39 06 94188455 or via email writing to <stefano.badessi@esa.int>.

In order to help interactions with and among AQS users, we have also created a closed Facebook Group called “Air Quality Sensor” (https://www.facebook.com/groups/379123806012686/). Any AQP user can request registration.