Report Hydroponic Vertical Farm

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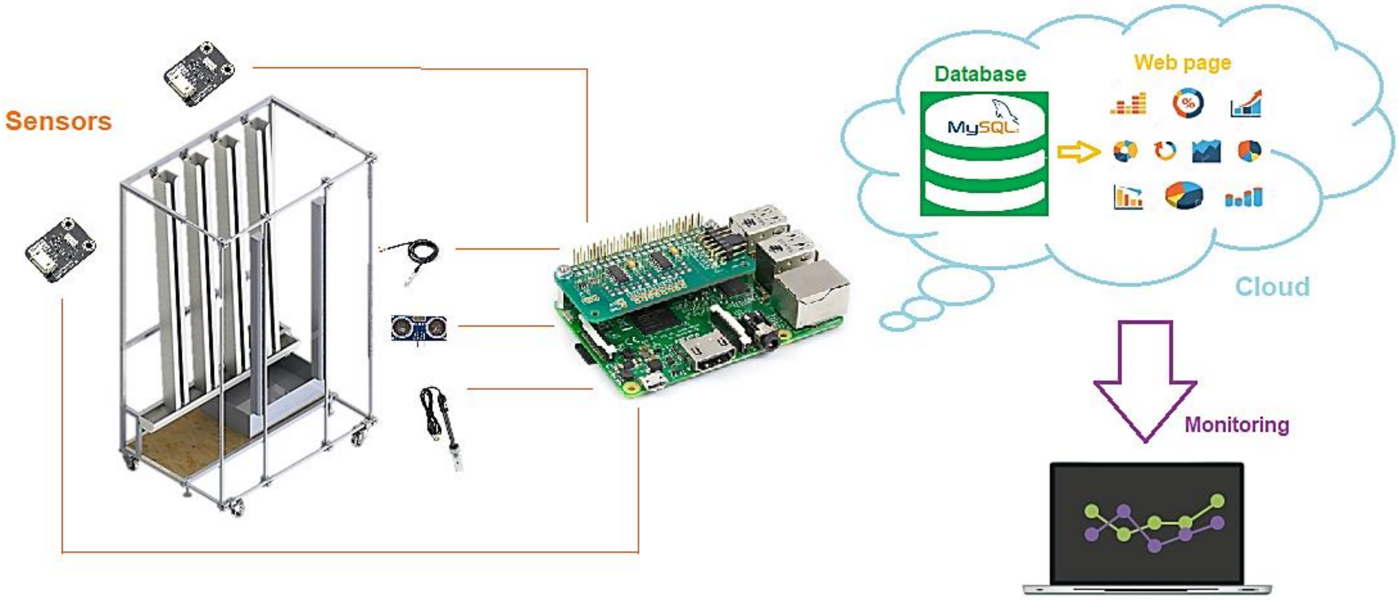
The project started from a collaboration between the "Alert Lab" (University of Liverpool) and the startup "Farm Urban".

The goal of the project was to develop an affordable monitoring system for a hydroponic vertical farm in order to carry out a quantitative assessment of the system. Indeed, even if hydroponics has been largely investigated in the recent years, it still needs a quantitative assessment to understand which are the main features playing a crucial role in the system.

In our case a vertical farm has been adopted. When dealing with vertical farms, the crops are collected in vertical structures called "towers". There is a medium inside each tower and its only role is to provide an anchorage to the plants. It is usually composed of inert material in order not to interact with the roots. As in hydroponics no soil is present, a solutions rich of nutrients is used in order to provide the plants with all the elements they need to grow. This solution is pumped from a tank to the top of each tower and then it flows down reaching the root zone. The solution in excess can then reach the tank again thanks to a gutter located under the towers, thus creating a closed loop system.



In the image above the main idea behind the project is represented: a group of selected sensors extracts useful data from the hydroponic frame (pH, EC, temperature, humidity, etc.). A Raspberry Pi reads all the data coming from the sensors and then it sends them to a remote database. The database stores all the data read during time and it is used as an access point to show the useful data in a web page. The web page is accessible from everywhere, so it is possible to monitor the system remotely.

Frame

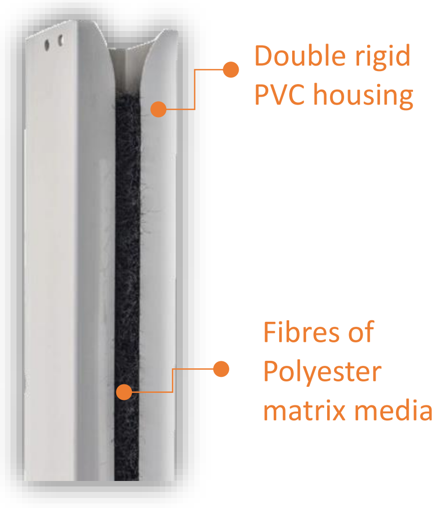
The frame has been designed in order to have a compact size and it can be moved easily using four castors wheels. The total height of the structure is 190mm so it is possible for it to pass through the alert lab doors. Only modular parts have been used for the structure: square and round aluminum tubes and connectors.

The frame is composed of two parts:

- Fixed part;
- Mobile (telescopic) part;

The fixed part is composed of square aluminum tubes of 25mm^2 outer size and 22.2mm^2 inner size coming from the old structure. The tubes are connected together using three way connectors and T-shape connectors.

The structure hosts four PVC towers hanged up using four hooks. A plastic gutter is also present collecting the water in excess coming from each tower. The gutter is indeed fixed to the structure with a light slope in order to allow the water flow back to the water tank.



Matrix Media:

- High porosity (50% air in volume)
- Reusable
- Support for roots
- Stable root zone temperature

A plastic box of 33L is used as a water tank. The dimensions of the box are reported below. The lid of the box has been modified to fit under the gutter and to host a slot for the sensors.

- **Dimensions**
  External: 710 x 440 x 165
  Internal: 605 x 370 x 145
  (length x width x depth in mm)
- **Weight**
  2,233g

The actual box is clear, but it strongly recommended using a white box in the future. It would reflect most of the light coming from the LED lights, keeping the temperature more under control.

Algae have been experienced inside the tank. The white solution could also help to reduce their presence.

A pump is used to pump the water through the pipes to the top of each tower providing the plants with all the nutrients they need to grow. It comes with a controller that can be used to control the flow rate. The typical flow rate has been used during the project is 30l/h. If the pump stops for some reasons, just increase the flow rate and then decrease it gradually. In case of algae growing on the pump, it should be turned off and cleaned thoroughly.

Features:

- (23W) Maximum flow rate of up to 2,500 litres/hour - adjustable from 750 - 2,500 litre/hour (in 8 steps)
- Electronic detection of no water enables automatic power off protection
- Soft start operation - pump gradually builds up to set flow rate
- Speed settings (30% - 100%) in 1% steps with power consumption indication - setting is retained if power is lost.

Dimensions: L x W x H (mm):

- 103 x 73 x 98 L x W x H (mm)

The pump should always be entirely submerged under the water or else it has been designed to stop working. For this reason, it is very important to control the water level constantly and fill the tank every time the level is too low.

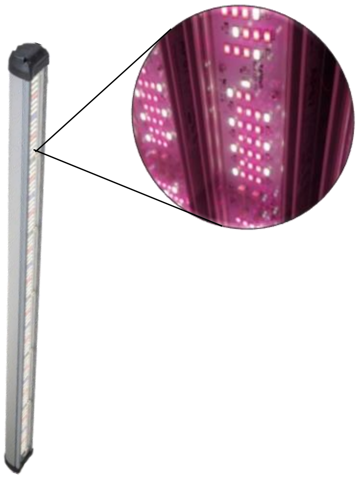
The water coming from the pump flows through an UV Sterilizer for sanity reasons. It indeed prevents the legionella from developing.

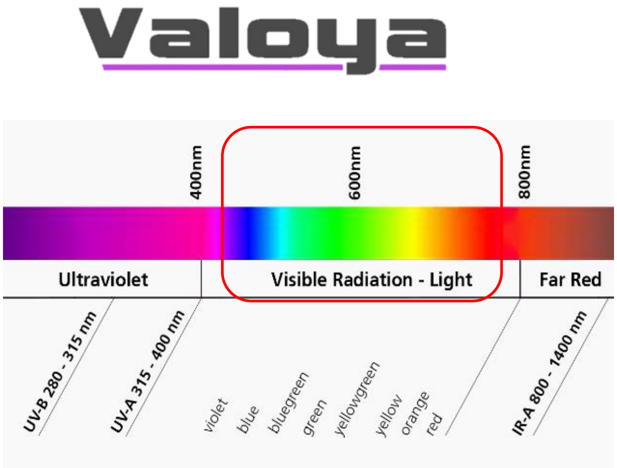
- **Dimensions**
  Length 300m, Depth, 70mm, Height 130mm
- **Maximum flow rate**
  360 lph
- **UV bulb size**
  G6T5 6w
- **Hose Size**
  From 1/2" to 1 1/4"

The sterilizer is composed of two plastic connectors, one for the solution coming from the water tank (input) and the other one for the sterilized solution (output). Algae can be stuck inside the connectors so it is important to check the condition of the connectors and clean them occasionally.

The mobile part is composed of round tubes connected using three ways clamps. The two central tubes have holes to host two LED lights.

The LED lights replicate the sunlight to provide the plants with the photons the need to carry out activities such as photosynthesis.





The two horizontal tubes have holes to adjust the distance of the telescopic part so to adjust the distance of the LED lights from the plants. Modern LED lights are now available in the market which are lighter and cheaper. A longer version is recommended so that the light distribution is uniform on the towers (some plants get more light than others causing a different growth rate).

Frame Cost:

	Bars	Connectors	tank	UV Sterilizer	pump	Towers	castors	LED lights	Adjustable feet	Total
Cost (£)	20	20	15	50	40	200	17	3296	24	3692

Sensors

The sensors has been selected to detect the important variables from the farm, paying attention to their cost.

A centered based Raspberry Pi has been adopted to read the sensors and then store the data in a database that can be accessible remotely so it is possible to monitor the system from everywhere.

It is possible to distinguish the sensors into two categories:

- Water sensors: pH, Electric Conductivity (EC), Water Level, Water Temperature;
- Ambient sensors: Temperature, Humidity, Pressure, Light;

The water sensors are used to check the condition of the solution inside the tank.

The EC sensor, detecting the electrical conductivity of the solution, gives an idea of the total amount of nutrients inside the tank.

SPECIFICATION

Signal Conversion Board

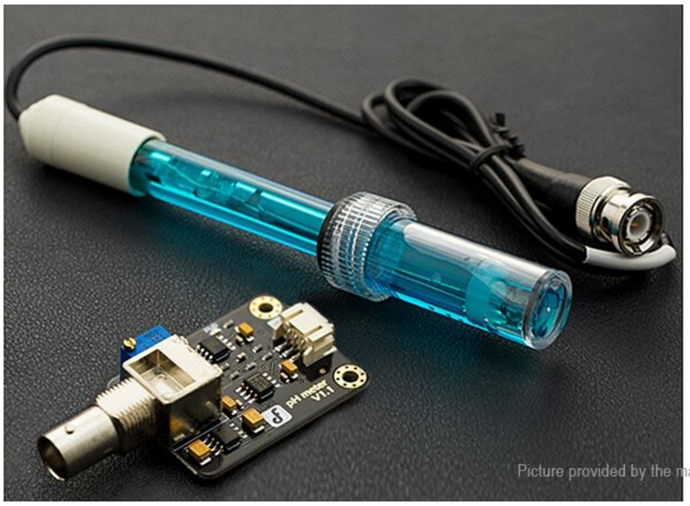
- Supply Voltage: 3.0~5.0V
- Output Voltage: 0~3.2V
- Probe Connector: BNC
- Signal Connector: PH2.0-3Pin
- Measurement Accuracy: ±5% F.S.
- Board size: 42mm*32mm/1.65in*1.26in

Electrical Conductivity Probe

- Probe Type: Laboratory Grade
- Cell Constant: 10±2
- Support Detection Range: 10~100ms/cm
- Temperature Range: 0~40°C
- Probe Life: >0.5 year (Actual life is related to frequency of use and scene)
- Cable Length: 100±2cm

The sensor comes with a calibration kit. The calibration process will be explained later.

The pH sensor detects the pH level in the water tank. The pH value must be in a specific range (depending on the crop) in order to make the nutrients available for the plants.



Picture provided by the manufacturer

SPECIFICATION

- Module Power : 5.00V
- Module Size : 43 x 32mm(1.69x1.26")
- Measuring Range :0 - 14PH
- Measuring Temperature: 0 - 60 ℃
- Accuracy : ± 0.1pH (25 ℃)
- Response Time : ≤ 1min
- pH Sensor with BNC Connector
- pH2.0 Interface (3 foot patch)
- Gain Adjustment Potentiometer
- Power Indicator LED

A calibration kit (pH buffer 4 & 7) has been bought to carry out the calibration of the sensor and it will be explained later.

Both the EC and the pH sensors are analog sensors so it was necessary to buy an analog to digital converter (ADC) shield for the Raspberry Pi. ACDPi, an 8 channel 17 bit analog to digital converter designed for Raspberry Pi has been chosen for the purpose. The reading process of the analog signals will be explained later.

Features

- 8 x 17-bit 0 to 5V Single Ended Inputs
- Control via the Raspberry Pi I2C port
- Stack up to 4 ADC Pi boards on a single Raspberry Pi
- Jumper selectable I2C addresses
- Buffered 5V I2C port
- Based on the MCP3424 from Microchip Technologies Inc
- Single Ended full-scale range of 5.0V
- On-board 2.048V reference voltage (Accuracy ± 0.05%, Drift: 15 ppm/°C)
- On-Board Programmable Gain Amplifier (PGA): Gains of 1, 2, 4 or 8
- Programmable Data Rate Options:
  - 3.75 SPS (17 bits)
  - 15 SPS (15 bits)
  - 60 SPS (13 bits)
  - 240 SPS (11 bits)
- One-Shot or Continuous Conversion Options

A DS18B20 has been used to measure the temperature of the solution inside the tank. It is simply a waterproof probe using the 1-Wire protocol to read the data. The temperature is another important indicator for the chemical reactions inside the tank.

SPECIFICATION

- Usable with 3.0V to 5.5V power/data
- ±0.5°C Accuracy from -10°C to +85°C
- Usable temperature range: -55 to 125°C (-67°F to +257°F)
- 9 to 12 bit selectable resolution
- Uses 1-Wire interface- requires only one digital pin for communication
- Unique 64 bit ID burned into chip
- Multiple sensors can share one pin
- Temperature-limit alarm system
- Query time is less than 750ms

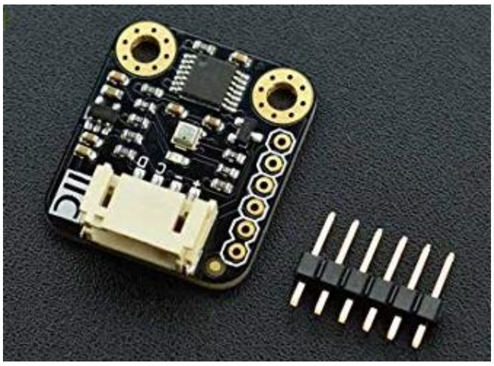
An HC-SR04 ultrasonic sensor is used to detect the level of the solution in the water tank.

HC-SR04 Specifications

- Working Voltage: DC 5V
- Working Current: 15mA
- Working Frequency: 40Hz
- Max Range: 4m
- Min Range: 2cm
- Measuring Angle: 15 degree
- Trigger Input Signal: 10µS TTL pulse
- Echo Output Signal Input TTL lever signal and the range in proportion
- Dimension 45 * 20 * 15mm

The ambient sensors are used to evaluate the conditions of the ambient surrounding the farm.

The BME280 weather sensor is used to measure the temperature, the pressure and the humidity of the ambient.



SPECIFICATION

- Working Voltage：3.3V~5.0V
- Working Current：2mA
- Working Temperature：-40℃~+85℃
- Temperature Measuring Range: -40℃~+85℃, resolution of 0.1℃, deviation of ±0.5℃
- Humidity Measuring Range: 0~100%RH, resolution of 0.1%RH, deviation of ±2%RH
- Pressure Measuring Range: 300~1100hPa
- Humidity Sampling Time: 1s
- Dimension: 22 * 25 mm/ 0.87 * 0.98 inches
- Weight: 12g

The VEML7700 ambient light sensor is used to measure the quantity of light coming from the LED lights. The idea would be to have some sensors spread in each tower to have a more precise assessment of the total amount of light distributed along each tower.

SPECIFICATION

- Supply Voltage: 3.3-5V
- Working Current: 45uA
- Shutdown Mode: 0.5uA
- Measuring Range: 0-120klx
- Accuracy: 0.0036 lx / ct
- Working Temperature: -25 ℃ ~ +85 ℃
- Dimension: 30 × 22 (mm) /1.81 x0.866 (inches)
- Weight: 12g

Both the ambient sensors have an I2C communication protocol, so they have been connected to the I2C dedicated pins in the Raspberry Pi GPIO (SCL, SDA pins).

Note: I could not manage to make the ambient light sensor work directly with the Raspberry Pi. The actual solution makes use of an Arduino UNO that reads the data coming from the sensor and it is then sent to the Raspberry Pi using a serial communication protocol.

Suggestion: search for another kind of sensor in order to avoid the use of the Arduino platform.

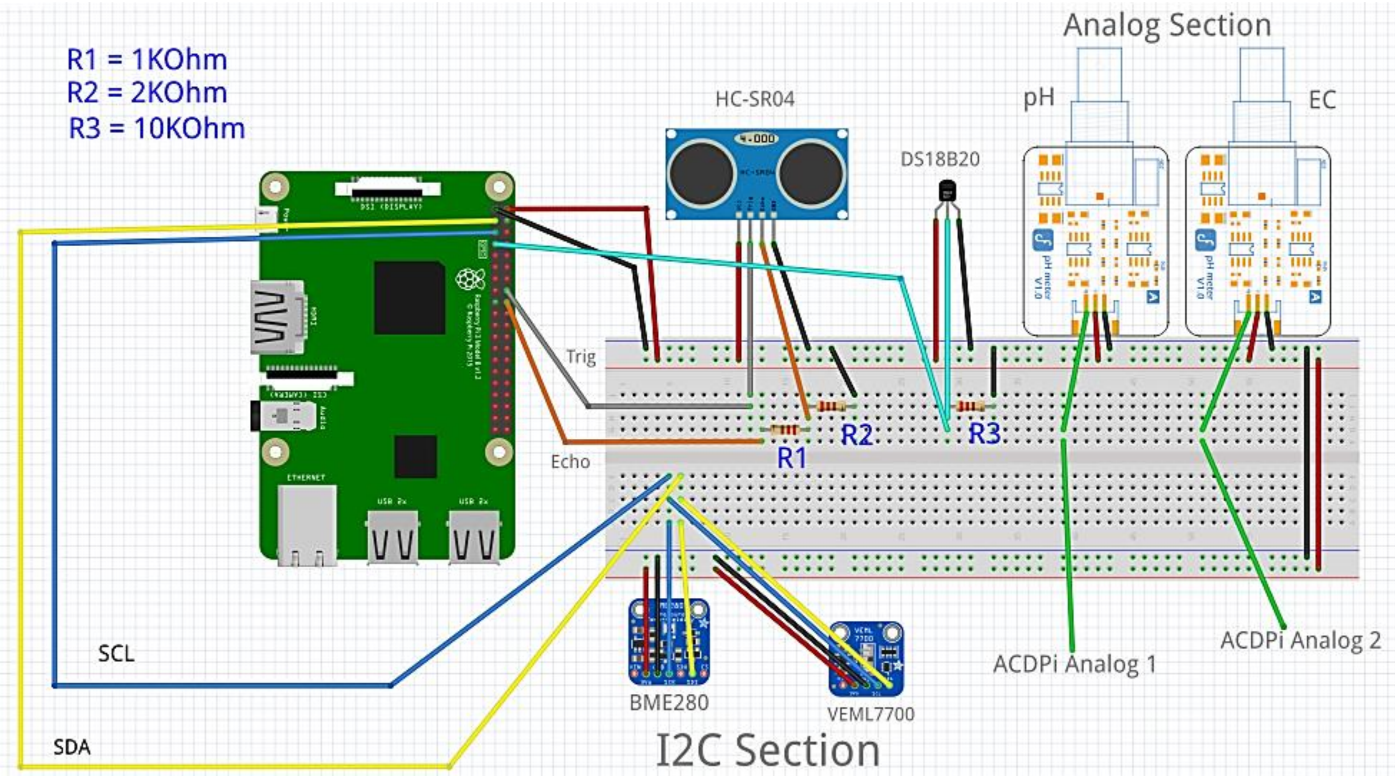
An Electric Box has been developed in order to store all the electric components inside a waterproof box. In the specific a plastic box has been chosen to store the Raspberry Pi platform, the ADC shield, a breadboard for the wiring connections, the Arduino platform.

8 waterproof connectors couples have been adopted in order to connect the sensors to the box.

The solution is very modular, composed with standard components, so it is possible to be replicated and used in other farms.

A Multicore cable has been used to connect the sensors with the connectors. In the specific is a screened waterproof 4 core cable of 25m length.

Note: the selected cable is too rigid for this application. A more flexible one would be preferable and cheaper as well.



	pH Kit	EC Kit	DS18B20	HC-SR04	BME280	VEML7700	Raspberry	ACDPi	Total
Cost (£)	28 + 6,20	53,69	5,30	3,70	11,52	7,60	30	16	162,01

	Box	Cable (25m)	Connectors (x8)	Total
Cost (£)	13,37	42,74	2,40	75,31

Total = 237.32 £

Note: the calibration kits (for pH and EC) should be removed from the total cost since they are just initial investments. Besides, the cable is longer than needed, so it can be used for more than one farm.

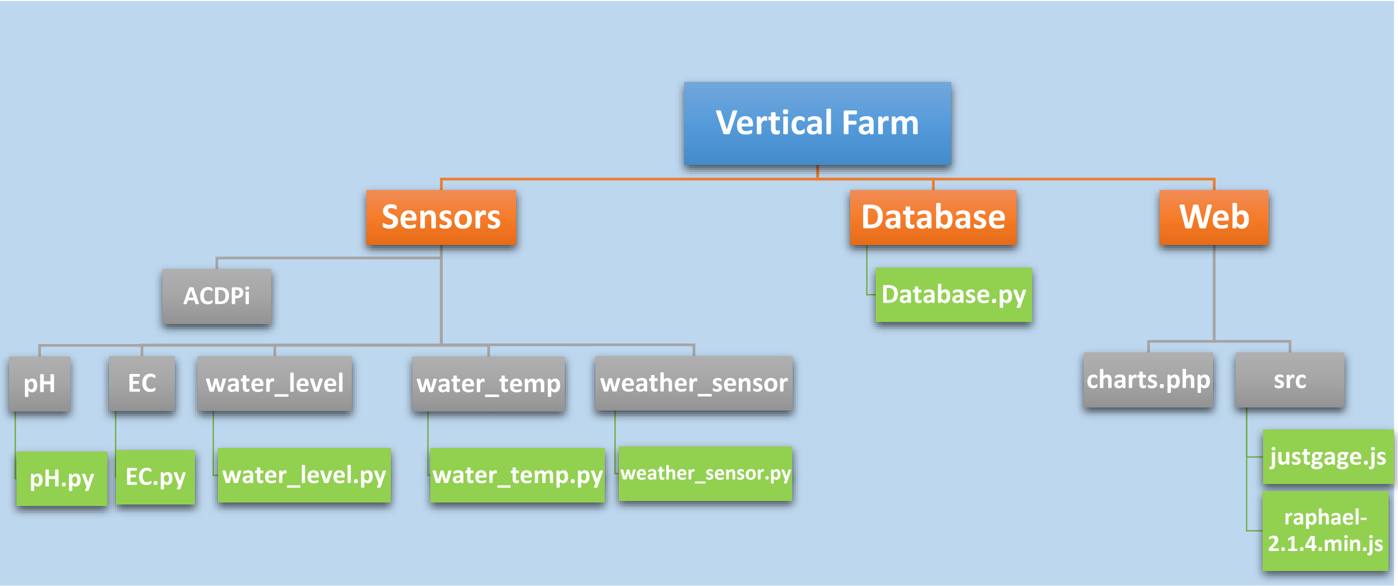
Software

Python language has been used to develop the part of the software for data reading and data storing. The software is composed of three main parts:

1) *Sensors*: here there are all the scripts which let us read the values coming from the sensors.

2) *Database* : here there is the script that creates the interface between the sensors and the database. The script recalls the functions from the sensors script to store the variables in the database and the datetime of the readings.

3) *Web* : here there are the scripts to create the web page and display the values from the sensors.



Sensors

The "Sensors" folder contains all the python scripts useful to read the data coming from each sensor.

ACDPI

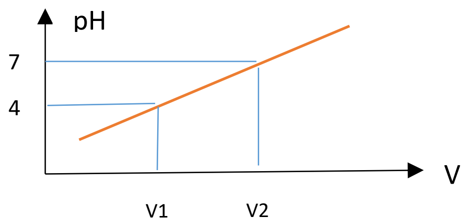
As mentioned earlier, both pH and EC sensors are analog sensors. As Raspberry Pi is not capable of dealing with analog sensors, it was necessary to add an analog to digital converter. The selected converter is a shield designed for the Raspberry Pi. It can be mounted directly over the GPIO pins like a simple extension. The analog sensors are connected to the analog slots available in the shield and the signal is converted in digital. Inside this folder there are all the functions needed to read the data from the shield. In the specific:

- ACDPi (*address1, address2, sample bitrate*) → initialize an ACDPi object
  - *address1* & *address2* refers to the I2C addresses of the shield (it depends on the configuration of the shield → check ACDPi documentation)
  - *sample bitrate* refers to the bitrate used to digitalize the signal (12,14,16,18)

- read_voltage(*ch*) → function used to read the signal coming from the sensor
  - *ch* refers to the channel related to the specific sensor

pH

The pH sensor has been connected to the channel n° 2 of the ACDPi shield (*ch* = 2). In order to know the relation between the voltage output (V) and the pH value, a calibration process has been carried out using the pH buffers (4 & 7). The buffers are simply two containers containing with a liquid whose pH in known. A linear relationship between V and pH has been adopted, starting from the output values related to pH = 4 and pH = 7.



EC

The EC sensor has been connected to the channel n°1 of the ACDPi shield (*ch* = 1). All the process used to read the values coming from the EC sensor is exactly the same as the one used for the pH sensor (including the calibration process). The calibration of both the sensors should be done regularly to check the validity of their readings.

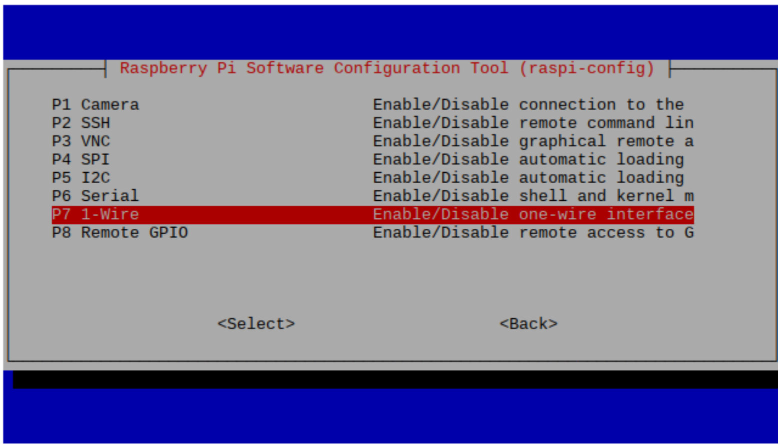
water_level

The level of the water inside the tank is measured using and ultrasonic sensor. The sensor is located above the water tank so it capable of detecting its distance from the water surface (d). Knowing the distance between the sensor and the bottom of the tank (D) it hence easy to get the level of the water left inside the tank:

$$Water\ Level = D - d$$

water_temp

The sensor used to measure the temperature inside the tank makes use of the so-called "1-Wire" protocol. The Raspberry Pi has a 1-Wire interface that has to be enabled in order to communicate with the sensor (Raspberry Pi configuration setting).



Once the 1-Wire has been enabled, the sensor can be connected to one of the GPIO pins to send the data to the Raspberry Pi.

weather_sensor

The weather sensor detects the temperature, humidity and pressure of the ambient. It uses an I2C protocol, so it is connected to the SCL (clock) and SDA (data) pins of the GPIO. Once again, the I2C has to be enabled to make the Raspberry Pi communicate with the sensor (Raspberry Pi configuration setting). The sensor needs a specific library to work called BME280, so it is necessary to install this library before using the sensor.

Database

The "Database" folder contains the script to insert all the data into a database. The database used in this project is a remote one called "Remote MySQL" (https://remotemysql.com/). It is a free remote database based on SQL language. It can be modified in PhPMyAdmin section using the following credentials:

- username: o0sRSRjnwl
- password: n4J1tq4yYW

Since this is a free version, the credentials cannot be changed and there is a limited storage size of 100MB.

The database has a "Table" called "hydroponics_vertical_farm" where all the data are collected. It is structured in rows and columns, where the columns are the different sensors, while the rows are the values read during time. Its structure can be edited, so it is possible for example to add or remove data anytime.

First, it is necessary to install "MySQL" on Raspberry Pi in order to start a communication with the database. Then, the bind address has to be changed using 0.0.0.0 in order to remove the local connection (sudo nano /etc/mysql/mariadb.conf.d/50-server.cnf → bind-address = 0.0.0.0). At this point the script makes the Raspberry Pi communicate directly with the remote database. The script reads the values from each sensor and then sends them to the database.

This process can be done automatically using "crontab", letting the script run every *tot* time. The actual code runs every hour, but it can be changed editing the crontab file (crontab –e).

Web

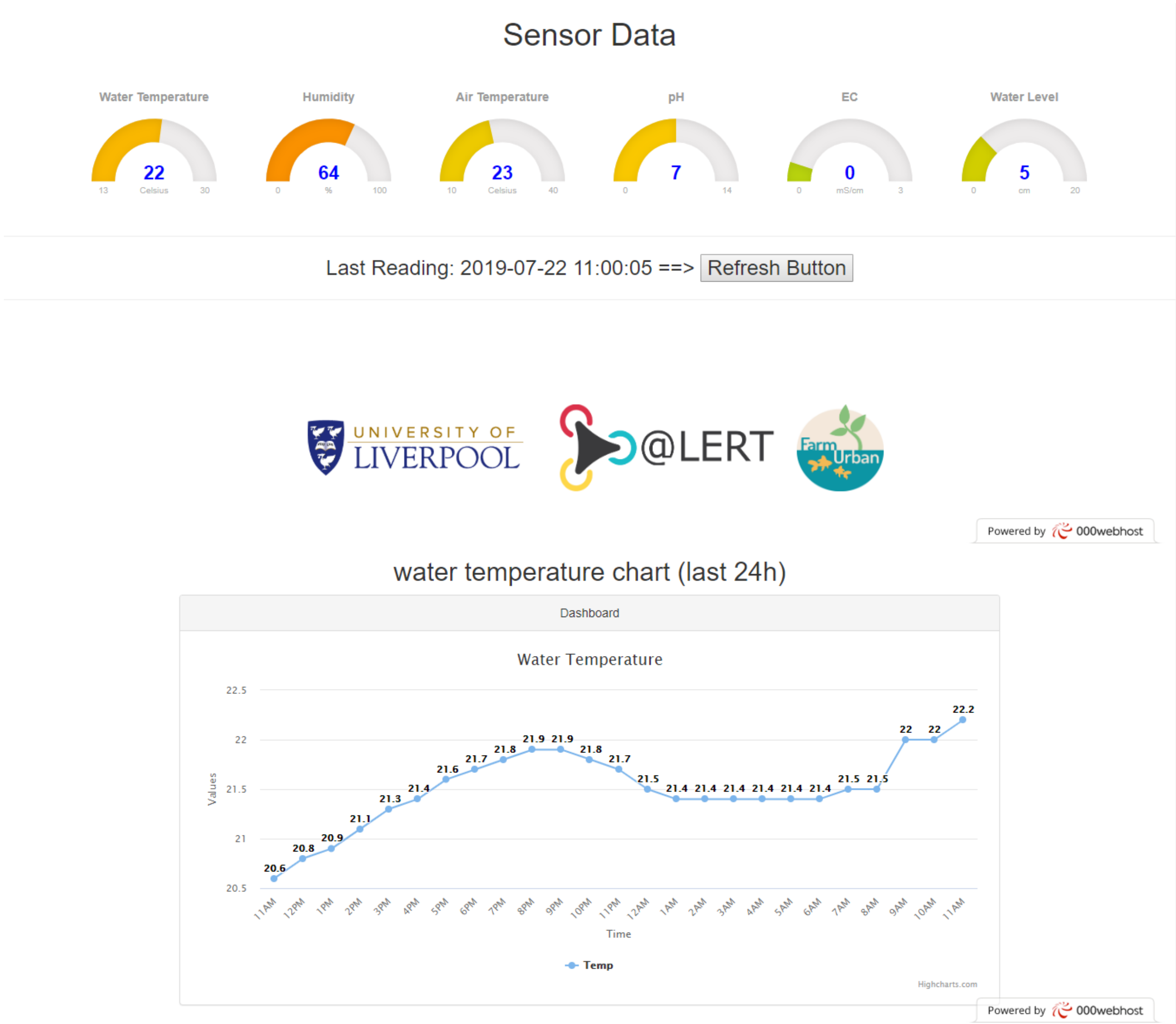
The "Web" folder contains the script (.php) used to show the data. In the specific, the file "charts.php" has access to the remote database and it is used to develop a web page containing the plotted data. The "src" folder contains the javascripts used to plot the last values in a graphic way. The web page has a refresh button that refreshes the page if pressed. A chart has also been added at the bottom of the page to plot the water temperature in the last 24 hours. The web page is hosted in a "free webpages host" called "000 webhost" (https://it.000webhost.com/). The credentials are:

- email: alertlab@liverpool.ac.uk
- password: alert

The name of the webpage is "hydroponicsvertical" and the password to edit it is "SharedRobot2019".

The web page is accessible from everywhere at this address:

https://hydroponicsvertical.000webhostapp.com/



Tasks and Future Work

As mentioned earlier, the tank has to be refilled manually. The max water consumption occurred during the first month and a half. In particular, a consumption of 4L a day has been registered. The pump should always be under the water level to prevent it from turning off. The ultrasonic sensor can now be used to know exactly when to refill the tank. The nutrients are to be added in water with a concentration of 3mg (3mL) per L of water. pH level can be changed manually using pH Up&Down, paying attention not to alter the EC value of the solution.

During the project algae presence has been experienced. Algae are dangerous for the farm for two main reasons: first of all the take nutrients from the plants and second thing they can lead to biological illnesses. Some tips to prevent algae in the system: cover the water tank with a lid and make sure the light cannot reach the water (tank and gutter) and use peroxide to kill algae (3%).

The next steps of the project could be the automation of the refilling process. A big water reservoir and solenoid valves can be used for the purpose.